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New York's third subway under construction.

Figs. 1 to 30, pp. 730 to 765.

(From *Engineering News-Record.*)

I

Construction of a third general rapid-transit subway system was begun by New York City in March 1925 and is proceeding under high pressure. Contracts for about $100 000 000 of construction have been let to date (June 1926). This undertaking is one of the most remarkable governmental construction enterprises in history, its cost being greater than that of any other single municipal undertaking known. Its fixed structure will cost more than $400 000 000, and nearly $200 000 000 will be required for equipment and other expenditures. The system reaches out into four of the five boroughs of the city and will about double New York's subway facilities.

Many remarkable features are found in the work apart from size and cost. Present-day conditions make much more severe demands on the subway designer and builder than those of 25 years ago, when the first subway line in the city had just been put under construction. Natural and artificial obstacles — underground structures, narrow streets, crossings with other subways and tunnels as well as with aqueduct lines and large sewers — control the design at a great many points, and the location planning and structural design involve formidable problems in consequence. Special considerations of operating flexibility and of the passenger's convenience led to the adoption of a track arrangement involving several cases of complicated interweaving of tracks by over and undercrossings. Two-level construction is required in a number of streets, and three levels occur at several crossings. These and other comparisons with earlier subway work give the present system special technical interest.

Growing traffic demand. — Rapid-transit demand in New York City has grown steadily since the first subway lines were put into operation in 1904. For about 25 years prior to that time, the city had been served by elevated railways, which through gradual extension had increased to about 82 miles of

structure, carrying about 194 miles of track. The subway system added 23 miles of structure with about 70 miles of single track, extended within the next few years to a total of 76 miles of track. At that time, the elevated railways were operating at an extreme congestion in the rush hours, a condition made worse by the interference caused by change from steam locomotives to multiple-unit electric cars, then in progress. The new subway lines, however, reached a substantially similar condition of crowding within five or six years, and long before 1913, when the second system of subways was placed under construction, conditions had become intolerable. This second system, totaling 102.2 route miles (partly subway and partly elevated) or 341.7 single-track miles, was much delayed in completion by the war; in consequence, when it was opened to traffic in 1918, it relieved conditions for only a short time, and soon was as fully taxed by the growing traffic as the old lines.

It was at once evident that an immediate beginning should be made on further extension of the system, not only to relieve existing traffic congestion but also to open up new suburban residential territory to permit spread of the population. Moreover, the city's business habits had in the two preceding decades largely readjusted themselves on a rapid-transit basis, as the great decrease in surface-car traffic made evident. Thus, the growth of rapid-transit demand was dependent not only on increase of population and built-up area, but also on increased rapid-transit demand per capita. Present rapid-transit traffic is about 270 rides per capita per year, as against 180 surface-car rides per capita (total rides 450 per capita). Of the rapid-transit traffic about 60 to 65 % is subway and the remainder elevated.

Under the pressure of the obvious demand, planning for rapid-transit extension went on in various forms and in the face of many financial and political difficulties, until two years ago, when the city authorities agreed on the Central Park West line, one of the important elements of the system now being built. Continued planning finally led to the adoption, in May 1925, of a comprehensive system composed of a double trunk in the midtown section of the Borough of Manhattan with five arms reaching out, respectively, to Upper Manhattan, western Bronx, southern and central Brooklyn, and the Queens-Jamaica region. With but minor modifications, mainly in the arrangement of lines serving the central Brooklyn area, this is the system now being built.

General routing — When the earlier subway systems of New York were laid out, the business center responsible for creating the traffic peaks was located on the southern tip of Manhattan Island, south of City Hall. Since then development of the midtown section, 23rd to 59th Streets, has made this section, relative to traffic, an important competitor of the Wall Street section. The shift of business location and daytime activity has an important influence on the layout of the new system. Whereas in the earlier systems the lines from Brooklyn and from the northern parts of Manhattan and Bronx Boroughs led as directly as possible to the Wall Street neighborhood, where the principal distribution and pick-up of passengers was looked for, the new system centers in a double midtown trunk line extending from 53rd Street south to 8th Street, through Eighth Avenue and Sixth Avenue.

This arrangement was adopted in spite of the remarkable difficulties faced by additional subway construction in Sixth Avenue. The street is already occupied by an elevated-railway structure; below ground is the double-track subway and tunnel line of the Hudson & Manhattan Railway, and in the worst section, extending from 31st to 34th

Streets, there cross the Broadway subway line of the B. M. T. (Brooklyn-Manhattan-Transit Corporation) system and (considerably deeper down) the crosstown tunnels of the Pennsylvania Railroad in 31st and 33rd Streets. At this crossing point therefore, the new Sixth Avenue subway must be placed at such depth below surface that it will pass over the Pennsylvania tunnels and under the other two subways.

At its northwest corner the double trunk line, united by a 53rd Street link, connects with the Central Park West line already mentioned as the first to have been determined upon. This line extends up Central Park West, Eighth Avenue and St. Nicholas Avenue to 156th Street, branching thence 1) eastward to a tunnel crossing of the Harlem River and through 162nd Street to the Grand Boulevard, along which it extends north to Bedford Park Boulevard, and 2) north through St. Nicholas Avenue and Fort Washington Avenue to the Harlem River ship canal — the northern end of Manhattan Island, within about three miles of the northern city line.

The north end of the midtown trunk section also has an easterly connection in 53rd Street with a line extending across the East River and some 10 miles east to Jamaica, running mainly through Queens Boulevard and Hillside Avenue, principal traffic arteries of the central part of the borough of Queens. Much of this line taps territory now lacking rapid-transit service, though well crossed by lines of the Long Island Railroad. The latter road has for some years past complained that its terminal facilities are insufficient to care for the traffic originating within the city, and has urged that the city should provide its own rapid-transit lines to deal with this traffic. The new Jamaica line as well as the Flushing extension (just being completed) of the present Queens elevated lines will take care of this difficulty.

At the south end of the midtown section two other lines lead southward and eastward respectively, branching from a short eight-track section developed by the meeting of the Sixth and Eighth Avenue lines. The southerly route passes down along Sixth Avenue extended (not yet opened up) and Church Street to Fulton Street, turning here to cross the East River to a junction with the easterly branch, which traverses the densely populated lower East Side. Two extensions into Brooklyn extend eastward along a main population axis, and southeastward to a junction with the existing Gravesend Avenue elevated-railway line of the Brooklyn-Manhattan-Transit system, which under the city's contract with that company may be recaptured and integrated with the new system.

Track arrangement and crossings. — With a view to developing full capacity of all the main tracks of the system, the branching and crossing points have in general been developed by the construction of diverging subways which cross over or under the main tracks.

The complex crossing layouts occurring at the north and south ends of the midtown trunk section are shown in perspective drawing on figures 3 and 7. It may be seen from these views how the intermeshing of lines serves to complicate and increase the cost of the system.

Special track arrangement. — Most of the new network consists either of four-track or of two-track line. In the former, normally the two central tracks are intended for express service and the outer tracks for local service. However, in order to serve the public's convenience, this arrangement is departed from in certain sections; in other sections the street is too narrow to accommodate four tracks side by side, requiring double deck arrangement.

A prominent instance occurs on the Eighth Avenue line, now under contract. This line extends for a distance of

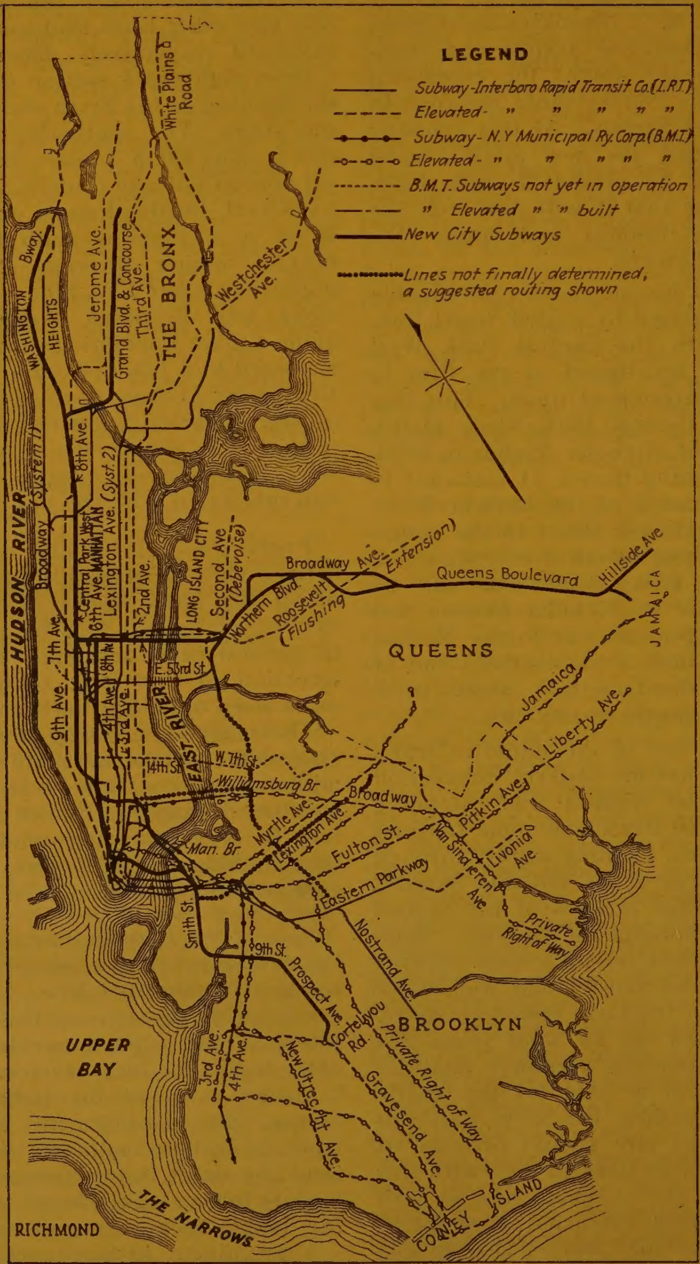
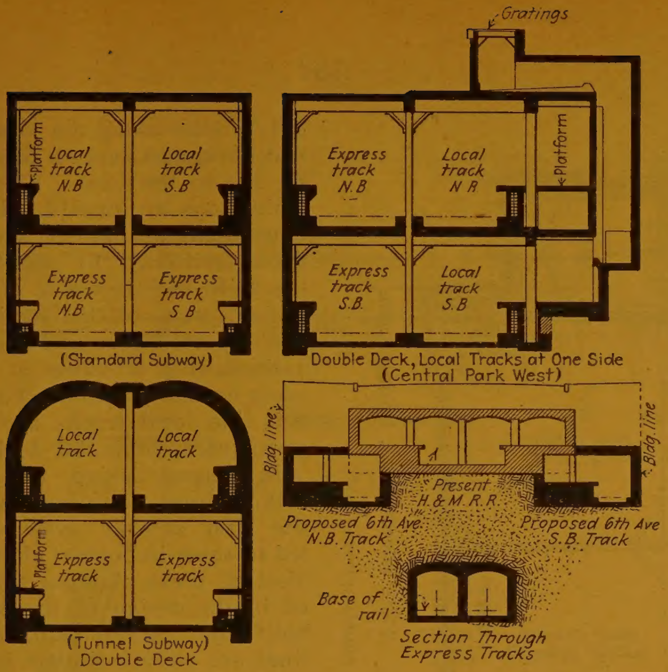


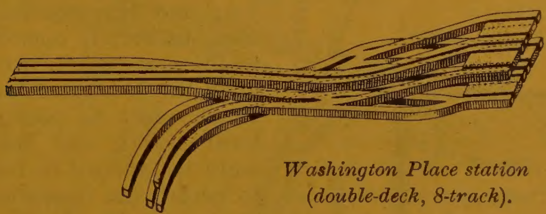
Fig. 1. — New York's rapid-transit lines, old and new.



Local track above express track (St. Nicholas Avenue).

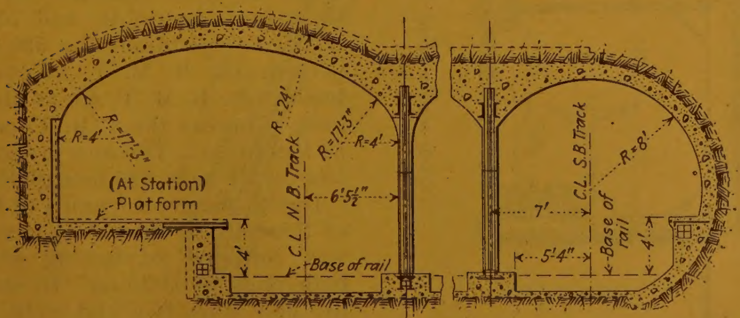
Proposed construction in 6th Avenue near 28th Street.

Fig. 2. — Some special track arrangements.



Washington Place station (double-deck, 8-track).

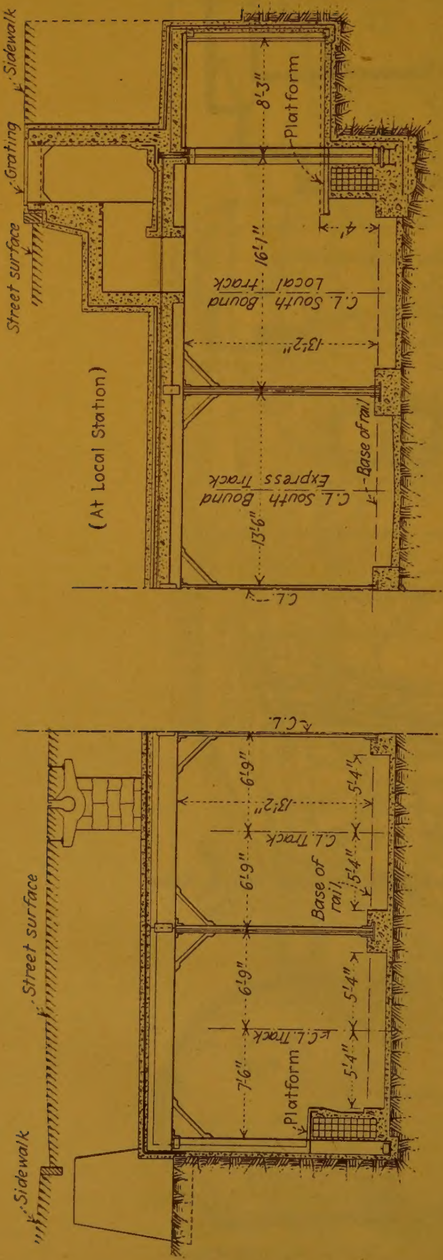
Fig. 3. — Junction at South end of Sixth-Eighth Avenue trunk-lines.



Typical station in rock tunnel, Half section looking North.

Typical two-track section in rock tunnel. Half section looking South.

Fig. 4. — Rock tunnel type.



Cross section along 8th Avenue. 116th Street Station, looking South.

Fig. 5. — Normal steel-frame box construction.

2 1/2 miles along the west side of Central Park, and here all the tributary traffic lies to the west. Since no express-train stops are provided in this section, convenient use of the local tracks has been facilitated by shifting these two tracks to the west side of the structure. At both ends of this section, the tracks are deflected over and under each other (eliminating crossings at grade) to resume normal position. Farther north on this line local tracks are above the express tracks in double-deck structure.

In general design, the new subways follow closely the practice established in the first subway system. Experience led to some important changes, however. Most of these changes were incorporated in the design of the second system, built from 1913 to 1920, and the present lines are closely similar to the latter in structure.

Important changes from prior designs. — In the first subway system the local stations were originally built 200 feet long and the express stations 350 feet long, to permit operation of 5-car local trains and 8-car express trains. Thereafter the local stations were lengthened to 225 feet to permit operating 6-car local trains and the express stations were lengthened to from 435 to 480 feet to permit the operation of 10-car trains. In the second subway system the maximum platform lengths were 480 feet for I. R. T. (Interborough Rapid Transit Company) operation and 530 feet for B. M. T. operation; the 530-foot length permits the B. M. T. to operate 8-car trains (the B. M. T. car is about 67 feet long, whereas the I. R. T. car is about 52 feet long). The new system, as noted later, will have 600-foot platforms.

Due to the great lengths of the stations of this second subway system, the plan was initiated of having entrances at both ends of stations. In the work on the new lines two and even more controls will be provided for the stations.

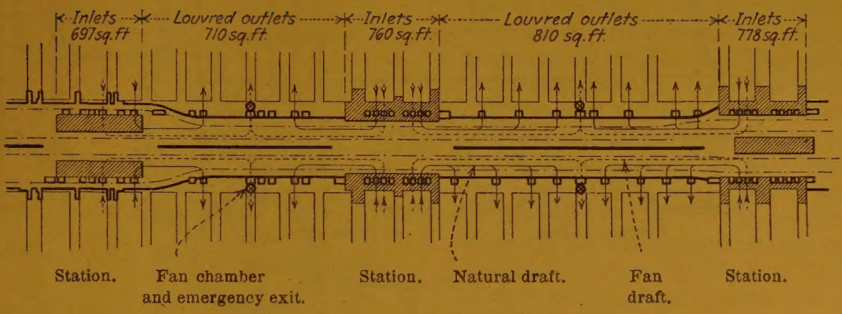


Fig. 6 — Typical plan of ventilation facilities.

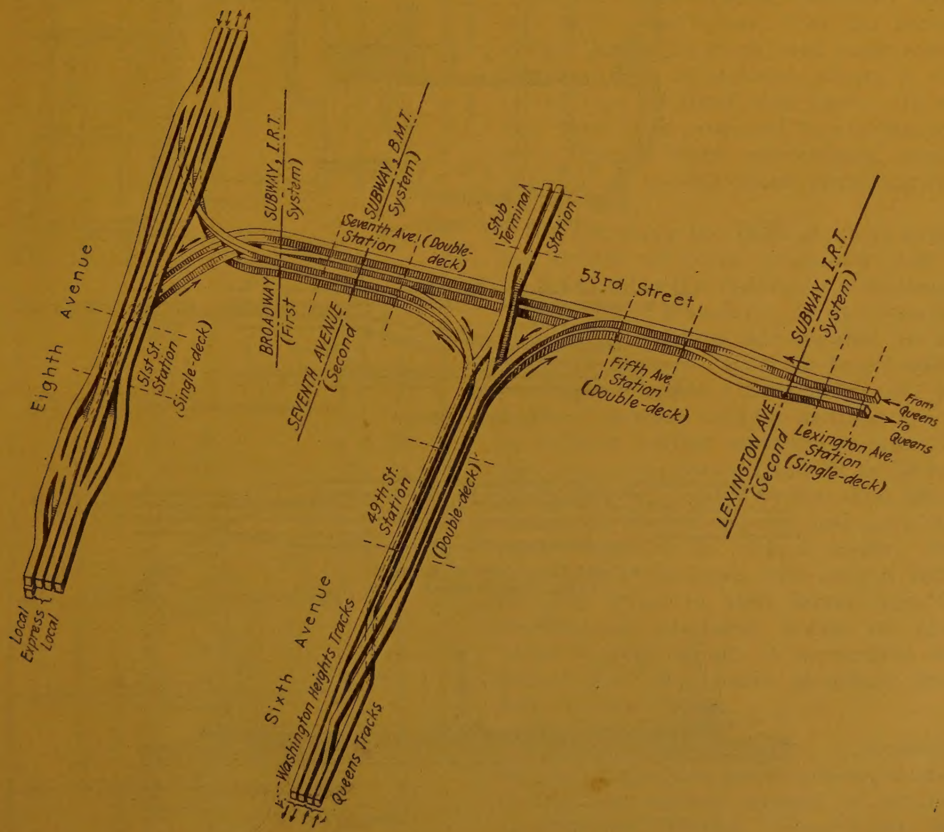
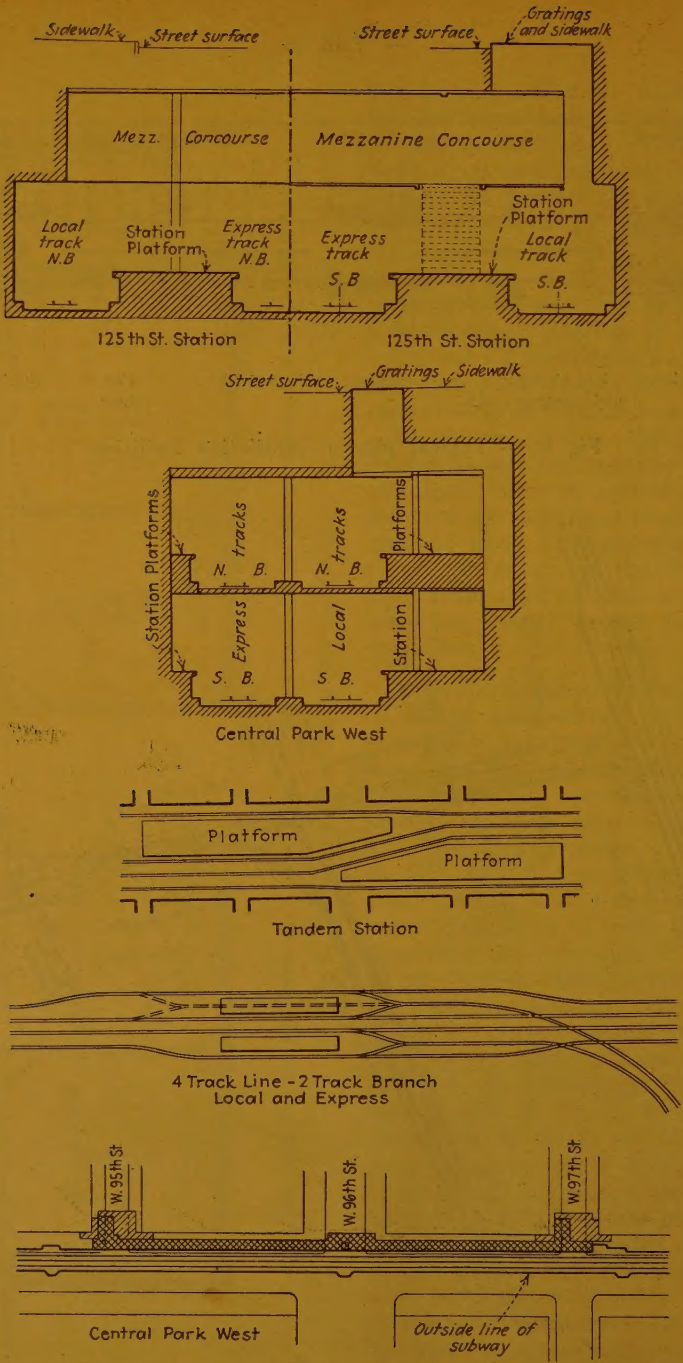


Fig. 7. — Junction of Sixth and Eighth Avenue trunk lines with 53rd Street line to Queens.



Double-deck local station at one side.

Fig. 8. — Some typical station layouts.

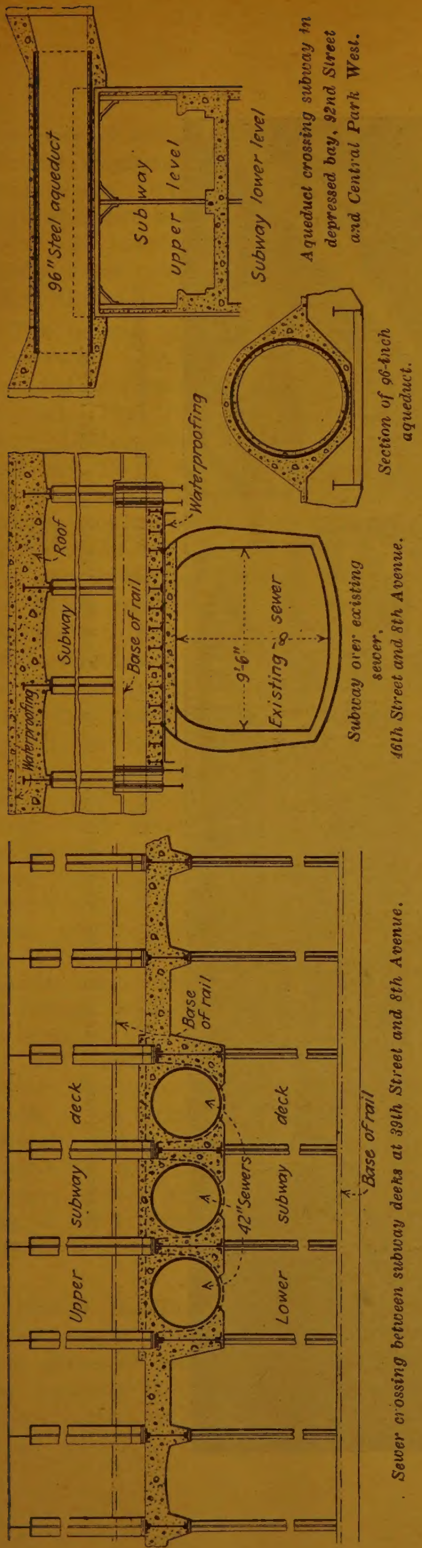


Fig. 9. — Special construction at sewer and aqueduct crossings.

Long mezzanines are to be provided where feasible, with a number of narrow stairways between the platform and mezzanine, to make walking along platforms unnecessary, so far as possible.

In the first subway system some ventilation construction was added after the line was completed. In the second subway system definite provision was made for change of air, to be accomplished normally by the piston action of trains and when necessary by fans to be used in emergency when trains are stopped. In the third or new system, this plan is being followed with only slight modification from the second system.

On the first system, ballasted track was used everywhere. On the second system ballasted track was used everywhere except at stations, where a concreted type of track was used. On the new lines it is proposed to use the concrete type of track everywhere, except possibly at special work requiring ballasted track.

Intense study has been given to avoiding delays in train operation due to track layouts. To reduce to a minimum delays due to transfer, a greater number of express stations are located in the midtown district. In order to get wider platforms within the limits of the 100-foot streets, tandem stations are to be built at certain strategic points. By this means platforms from 30 to 36 feet wide will be possible at the 42nd Street station on Eighth Avenue, instead of the more usual 22 to 24-foot width. The southbound platform will extend south of 42nd Street to 40th Street, and the northbound platform north of 42nd Street to 44th Street. A mezzanine will extend over the entire structure from 40th to 44th Streets.

General structural type. — Rectangular steel-frame box construction, as used in the first subway system, is retained as the general type. Experience has shown it to be satisfactory in all respects, well adapted to speed and con-

Fig. 10. — Steel-frame box construction, typical of new system as well as its predecessors.

Six-track subway structure under erection in rock cut in St. Nicholas Avenue near 131st Street.

venience of construction, and free from service troubles or the development of weaknesses. Where the line is at considerable depth below the surface in solid rock concrete-lined tunnels are used, and at river crossings circular cast-iron-lined shield-driven tunnels.

The normal structure, exemplified by a drawing (fig. 5), is somewhat larger than the first subway line and part of the second. The dimensions originally used were 13 feet clear height from base of rail and 12 ft. 6 in. track spacing. In the lines of the second system, the clear height was increased to 13 ft. 2 in. (except for 15 feet in Fourth Avenue, Brooklyn, and in the Center Street loop), while the track spacing on the lines of the Brooklyn Company (B. M. T.) of the second system was increased to 13 ft. 6 in. to admit larger cars. These dimensions of 13 ft. 2 in. height and 13 ft. 6 in. track spacing are used also in the new system.

The framework consists of steel transverse bents, with columns in the side walls and between tracks carrying a transverse roof beam 18 to 24 inches deep in single-track lengths. The columns rest on concrete pedestals formed into continuous longitudinal footing walls under each row of columns. However, where the floor of the structure is below ground-water level, the floor is designed as a reinforced-concrete slab of sufficient strength to resist hydrostatic pressure and to distribute the loads of the structure through substantially the entire floor area. The typical roof-load distribution assumed in the design as well as the size and axle loading of the typical subway cars are indicated on figure 6.

Design loading and stresses. — A statement of the essential design data was given in unusually informing manner recently before the Municipal Engineers Society of New York by A. I. Raisman, Division Engineer in charge of design for the Board of Transportation :

« *Subway Loading.* — The subway is in general designed to carry the dead-load above it and a live-load of at least 600 lb. per square foot. Under the roadway the structure is made strong enough to permit the operation of 100-ton trucks with axles spaced 12 feet centers and with wheels of 6-foot gage. The specifications provide that the structure be sufficient to carry the heaviest trolley cars — the maximum being the 50-ton ash car, 38 feet long. The 100-ton truck in general gives greater loading than the trolley car. The assumption is made that the pavement distributes the wheel load over an area of 2 × 2 feet and that the load is spread out through the earth below at an angle of 30° with the vertical. As a result of a study of this matter it is found that a loading of 1 500 lb. per square foot to include dead-and live-load is a good compromise figure for depths of cover up to 9 feet from the underside of roof to the street surface, and that is the usual basis of design.

« This live-load has been considered rather high by some engineers who are used to the design of bridges. I recall that in the Cambridge subway a live-load of from 200 to 300 lb. was considered sufficient. The most direct illustration to combat this position is a picture showing brick or other building materials piled up 8 or 10 feet high in front of a building under construction. This represents a loading of 1 000 to 1 200 lb. per square foot. It is thought that the use of a street should not be limited by reason of the construction of a subway beneath it.

« It might be interesting to state here that when the first subway was built the assumed live-load was varied, depending upon the character of the neighborhood. The section north of 59th Street was expected to remain entirely residential and a live-load of 500 lb. was considered sufficient. South of 59th Street, in the « medium » business dis-

tricts, the center spans were designed to take a loading of 690 lb. and the side spans 950 lb. per square foot. In the heavy business districts the center spans

Fig. 11. — Subway construction facilitated by modern machinery.

Power shovel excavating under timber street deck.

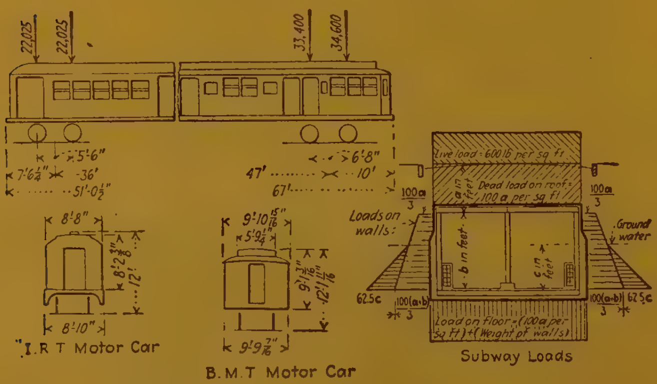


Fig. 12. — Roof-load and car diagram.

were designed for 1 000 lb. and the side spans for 1 135 lb. per square foot. These heavier loadings for side spans were assumed to provide for falling walls of buildings due to fire. However, the assumed live-loads were reduced as the cover increased beyond 5 feet, which was the depth usually sought. It is

believed that the present assumptions are satisfactory and should be continued. At least the distinction between residential, medium and heavy business districts was completely upset by later growth.

« A fiber stress of 20 000 lb. per square inch is permitted for steel in bending. Where the compression flanges are firmly embedded in concrete so as to make practically a reinforced-concrete structure a stress of 25 000 lb. is permitted. In columns the permissible stress varies in accordance with a straight-line formula with a maximum of 14 000 lb. per square inch. These high stresses are permitted in view of the very heavy loads that are assumed. However, it should be noted that it is the present-day tendency to increase the allowable stresses. The American Society committee recommended an increase from 15 000 to 20 000 lb.

« Here it might be of interest to note that on two or three occasions, as the result of derailment, from two to six intermediate columns have been knocked out, without apparently doing any permanent damage to the subway. The beams or girders are not in general spliced over the columns to transmit bending, but when the columns were gone the roof remained stationary in spite of our usual ideas on the subject. The natural assumption is that an arching effect took place in the pavement, in the earth fill with its pipes, etc., and also in the steel and concrete of the roof, which carried the load over to the adjacent solid supports. Naturally also, as soon as the accident occurred the street traffic was roped off of the area above and speedy efforts were made to put in temporary supports. »

The track loading from subway trains amounts to about 1 ton per linear foot of track.

The steel framework as described contains no longitudinal steel members except at stations. The bents thus are quite independent, which is held to be an advantage in construction, as it permits a considerable variation of the position of bents if local conditions make this desirable. The side walls and the roof are formed of jack arches of concrete between the columns and the transverse beams, with crown thickness of 7 inches. Waterproofing (used only on the roof and below water level) is applied outside of this thickness and in turn is protected by a layer of concrete or (where the water pressures are high) by 4 to 8 inches of brickwork laid in mastic. These features of construction are substantially identical with those of the first subway. However, the knee-braces then provided to stiffen the connection of roof beams to columns are not used in the present design, and the bulb-angle columns of the first subway are replaced by built I-columns of plates and angles.

Concrete partition walls are built between tracks of opposite traffic direction (except at stations, crossovers and other special points). Near switches a wall is also constructed in the intermediate column line, for protection to the structure in case of derailment. The central partition wall was not used in the first subway system but was adopted in the second, as an aid in ventilation, to make the piston action of the trains effective in moving the air toward the ventilation outlets.

Duct benches about 2 feet wide and 4 feet high are constructed along either side wall, extending to car floor level. The top of these benches is available for use as a walk in case of an interruption to train service, when passengers must be allowed to leave stalled trains. These benches increase the width of the structure only slightly, as they can be built close to the car clearance line or about 5 ft. 5 in. from track center, which is 13 to 18 inches less than the required side wall clearance.

A complete system of ventilation in-

lets near the stations and outlets with exhaust fan chambers midway between stations is provided just as in the second subway system. The absence of adequate ventilation provision in the first subway system led to much trouble from excessive heat in the subway atmosphere in summer, and this was the reason for the design of the ventilating facilities in the second system. It has been found entirely successful and is retained in all essentials. Change of air every 15 minutes is desired, requiring usually about 800 square feet of openings at each station and midway between. Gratings over the openings are given 50 % excess area. A typical case of the ventilation arrangements is sketched in diagram plan on figure 6.

Special problems. — Many special structural problems have arisen from the various complicating conditions affecting the new system. In Sixth Avenue it is planned to arrange the tracks of the new system alongside and below the level of the Hudson & Manhattan subway. At many points sewers, aqueducts and other subsurface structures of large size must be accommodated, for which purpose various expedients are resorted to, as illustrated for the aqueduct crossing at 92nd Street and Central Park West and two sewer crossings.

Track. — Short block ties set in concrete are to be used for rail support throughout the new system, as compared with the ballasted track construction used throughout the first subway system and on most of the second system. In the latter, short block supports were used at stations, and the construction has been found so satisfactory as to lead to its adoption as standard.

Operating plan and stations. — The general operating plan of the existing subway systems — to provide by separate tracks for two types of traffic, express and local — is retained in the new system. An effort has been made, however, to correct some of the defects of this operating plan as it has developed in practice on the older systems. The local trains now rarely carry full load or operate at maximum track capacity. Further, there is so heavy a traffic interchange between local and express trains at the interchange stations as to slow up the movement of express traffic and therefore to reduce the capacity of the express tracks. Both effects cut down the carrying capacity of the system, and both are believed to be due in part to the rather close spacing of express stations and to the fact that the station layout facilitates interchange. The new system has been designed with longer station spacing, both express and local, except that in the midtown district almost all stations are express stations, so as to avoid long transfer stops in the congested districts. A great deal of study is being given to the problem of providing commodious facilities for passengers' transfer at points where lines intersect or join.

An operating plan for the five-branched system has not been fully worked out, but it will necessarily be complex. Care has been taken to lay out the system with such track interconnections and arrangements as to suit various schedules of operation. In particular the effort has been made to avoid bringing two tracks together into one or otherwise reducing the track capacity of the system at any point. This is not everywhere possible, as where the three tracks from the Grand Concourse and the four tracks on the upper Broadway line merge into four of the Central Park West stem.

Much care has been given to station layout, with a view to both convenience and maximum capacity. Operation of the older subway lines led to repeated increase in length of trains, requiring a large amount of costly extension of station platforms. Ten-car trains are the longest now operated in express service, and six-car trains in local service.

Operating engineers believe that the length of express train cannot be increased greatly without developing mechanical and electrical limitations, and that a train length of 14 or 15 cars will probably be found the maximum with present equipment. The stations on the new system have been laid out with 600-foot platforms, capable of being extended to 660 feet, to accommodate respectively 12 cars and 14 cars of 50 feet. So far as possible no stations are placed on curves, in which respect the present practice differs radically from that followed in the layout of the first subway, whose important stations are nearly all on curve. However, track radii of 2 000 feet or over are considered permissible at station platforms.

To facilitate train movement, any necessary crossovers between tracks are placed preferably at the leaving ends of stations rather than at the entering ends; and waiting trains are sorted for outbound tracks.

Alignment details. — In general, the attempt is made to limit curves on the new lines to 2 300-foot radius, without transition. However, for turning sharp corners, spiraled curves down to 600-foot radius are considered permissible, and at the tightest places radii as low as 350 feet have been used. In the original subway radii as small as 147.25 and 180 feet were permitted. Grades are kept below 3 % where possible, but this rate is exceeded at some very difficult points. In the earlier subways, maximum grades up to 4.5 and 5.3 % occur on the river approaches.

Progressive construction. — Largely because the Washington Heights-Central Park West route was first approved by the city authorities, construction began on this line, the first work being initiated about a year ago. At the present time, 17 contracts have been let for construction, covering the entire west side of the central loop and the Manhattan stem extending north from it to Harlem ship canal. The contract prices average around $2 000 000 per track-mile in Central Park West, $2 500 000 per track-mile in St. Nicholas Avenue and Fort Washington Avenue and $2 750 000 per track-mile in Eighth Avenue, with an overall average somewhat over $10 000 000 per mile of four-track structure. These figures include station finish and roadbed, but no third rail or signals or other equipment.

In view of the great magnitude of the work required to construct the entire system, careful thought has been given to the feasiblity of operating successively completed portions as integral units for the time being. The Board of Transportation believes that the Washington Heights and Eighth Avenue line down to the southern end of the present contracts in the neighborhood of Eighth Street can profitably be operated before other parts of the system are completed. This would not have been possible 20 or even 15 years ago, as the rush-hour traffic then sought the lower end of the city, but at present one-half to two-thirds of the traffic centers in the midtown section. The next work may follow on the line leading south to the Fulton Street crossing of the East River and on the 53rd Street crosstown line leading to the Jamaica connection. Operation of the initial line can be extended to these lines without difficulty.

Relation to present lines. — The essential plan of the new system is that it shall be an independent self-contained rapid transit network. However, the design is such that it could be operated by one of the present operating companies (Interborough Rapid Transit Co., mainly in Manhattan; Brooklyn-Manhattan Transit Corporation, mainly in Brooklyn) or by a third private corporation.

Cost and Financing. — The estimat-

ed total cost of the system is summarized in the table hereafter. The estimate as well as contract prices are more than double pre-war costs.

Prospective cost and earnings of new subway system of New York City.

Cost :	
Line, stations, track, yards, shops and buildings	$ 345 005 000
Equipment, including buildings, for power system	101 000 000
Real estate for construction and equipment	24 320 000
Culver line recapture	5 800 000
New culver terminal	640 000
Administration and engineering	30 000 000
Total, excluding interest during construction	$ 506 765 000
Traffic :	
Passengers per year, estimated	402 000 000
Income :	
From operation at 5-cent fare	$ 20 100 000
Other income	603 000
Total	$ 20 703 000
Less operating expense	13 366 500
Net operating income, available for capital charges	$ 7 336 500

The first subway system was built under a construction and operation contract as a result of public bidding for the entire system. The city in this case paid for the construction. The contractor built the structure with the aid of a number of sub-contractors, for the amount of his bid. He furnished the equipment and obtained the right to operate the line for 50 years, with a renewal privilege. The rental paid by the contractor is equal to the interest on the bonds issued for construction, plus 1 % annually for bond amortization.

For the second system the city entered into an operation and equipment agreement with each of two operating companies, whereby the city was to furnish the structure and the companies the equipment. Each company also contributed a certain amount of money toward the construction. Under their contracts each company was to retain a certain amount as a preferential after operating charges. Income in excess of this was to be paid as a rental to the city to an amount equal to a corresponding percentage on the bonds issued by the city for construction, and beyond this income, was to be divided equally between the city and the operating company. By reason of the heavily increased cost of operation since the war, the companies have not earned sufficient to pay their operating charges and preferentials and hence the city has received no return on its money invested in the second system. The construction was let by the city in sections to various contractors.

The new system is expected to be built and equipped entirely with city funds. The financial problem involved for the city is therefore much greater. It is a serious problem especially because the state law limits the bonding power of the city to 10 % of the total assessed valuation, and the available bonding capacity within this limit will not provide for more than half of the entire

project. It is proposed to meet part of the cost by construction loans to be met from the city's current revenues, and the remainder by assessments upon property benefited in the areas contiguous to the new lines. According to a statement by the chairman of the Board of Transportation a few months ago, the total cost could be raised by the issue of about \$240 000 000 of bonds, \$187 000 000 of short-term loans, \$138 000 000 of benefit assessment, and a small balance of current funds.

The cost of transportation on the new system will depend vitally on the method of financing adopted. By covering a material part of the cost of the line through benefit assessments and another part through tax funds, the values created by the new lines can be made to pay their share of the increased transportation costs arising from the expensive forms of subway construction necessitated by congested city conditions. It is believed that on this plan a 5-cent fare will make the system self-supporting. Operation and maintenance alone are estimated at 3 1/2 cents per passenger, ranging down to 3 cents later as traffic increases.

Organization. — The Board of Transportation, which is constructing this subway system, consists of John H. Delaney, chairman, and D. L. Ryan and William A. De Ford, commissioners The work is being designed and supervised by its engineering department, of which Robert Ridgway is chief engineer. Col. J. R. Slattery is deputy chief engineer in charge of construction, and Sverre Dahm is deputy chief engineer in charge of design. J. O. Shipman is engineer of the first division, John H. Myers of the second division, J. B. Snow of the tunnel division, H. N. Latey of equipment and operation, R. H. Jacobs of the track division, J. T. Kane of the station finish division and A. I. Raisman of the designs division.

As noted above, this project is very large, involving a great deal of money, and it is not practicable to start work on the entire project at once. It is expected to let an average of \$125 000 000 worth of work per year and it is hoped to have the system in operation in 1931.

II

« The operations described below by T. L. MacBean, Chief Engineer, Oakdale Contracting Co., New York, are no part of the third system of subways outlined in the first article of this series, but their description is pertinent to the new work because on them was developed the use of power excavation under decked streets which is the characteristic construction feature of the new subway.

« Subway construction on Long Island is represented by the Flushing extension in Queens and 14th Street line in Brooklyn. The Flushing extension is so called because it is the continuation of the Corona line now used jointly by the Interborough Rapid Transit and the Brooklyn-Manhattan Transit Companies. There have been three contracts on the extension, the first, the line west of Flushing Creek, the second the bridge over Flushing Creek and the third contract that part of the line in Flushing, L. I. The third contract is described here and consists of 550 feet of fill and open cut to the portal of the dead-end subway which is 1 650 feet long with a 600-foot end station. Only the subway construction is considered here. Construction on the 14th Street line, so-called because it is an extension of the 14th Street line on Manhattan Island, consists of 7 600 feet of subway undertaken in two contracts. The Flushing line costs \$1 600 000 and is virtually finished. The 14th Street line is under construction and the contract price is \$6 800 000; it is perhaps 60 % completed. Both lines are of the conventional two- and three-track design with concrete floor and steel bents with concrete jack-arch walls and roof. They are both cut-

and-cover operations. » (Editorial note, *Engineering News Record.*)

* * *

Power shovel excavation as a recognized subway construction process was inaugurated on the Flushing Extension in Queens and on the 14th Street line in Brooklyn of the New York subway system. As a part of the process there was developed the arch bracing system which gave a clear space for shovel operation and motor truck or train haulage while strongly supporting the roof and sides of the cut. This is the signal feature of the work done in recent years, across the East River from Manhattan, in subway construction. Its merit has carried it to the Philadelphia subway work as described in *Engineering News-Record,* 21 May 1925, and across the river to several Manhattan operations as will be described in succeeding articles. There were on this work in Brooklyn and Queens, noteworthy underpinning and concrete practices.

The two operations were conducted by the same organization, the Oakdale Contracting Co., with E. A. Herrick, general manager, the writer as chief engineer, and John H. C. Gregg, construction engineer. They represent, therefore, variations of the same planning thought as determined by different conditions and increased experience — the Flushing extension being built first and then the 14th Street line. Enumerating briefly the broad differences, they are :

1. A large part of the excavated material on the Flushing extension was hauled by industrial railway underground to the portal and then to a fill, while shafts about *five blocks* apart on the 14th Street line were used to hoist the material to over-street hoppers discharging into motor trucks.

2. Street widening was necessary on the Flushing extension but there were no major street structures, while on 14th Street there were a street railway and an elevated structure, also gas and water mains to be shifted outside the cut, but there was no widening.

3. Underpinning was light on the Flushing subway but complicated by ground water, while on 14th Street there was water only in places but some rather complicated problems of supporting structures were presented. Understanding of construction methods is helped by considering classes of work rather than individual contracts.

Timbering. — Timbering and excavation are coincident processes but it is more simple to consider them somewhat separately. The Flushing extension was the first under contract and the timbering plan was worked out there. As the street was narrow it had first to be widened as shown by figure 13. The basic idea of the contractor was to eliminate hand excavation — to use power shovels — and his timbering and excavating plan was conditioned on this object. As developed it was to open half the street with a shovel cut some 12 feet deep, then to timber and deck this cut, then repeat the operation for the other half of the street, finally to deepen the cuts by shovels working under the timbering. The timbering design as a first requisite had to provide clear shovel room for deepening the cuts.

As developed the design is shown by figure 14. This happens to be a plan for the 14th Street line where a car track had to be carried but the system on the Flushing line, as shown by figure 15, was substantially similar. In effect the square framing familiar in past subway practice is, below the first shovel cut, replaced by an « arch bracing » depicted by figures 14 and 15. Originally instead of using skew-back castings the ends of the raker braces were beveled. The castings (patentend) were a later development for improvement. They simplify the timbering : 1. by eliminating beveling and

Fig. 13. — Street widening operations on Flushing extension.

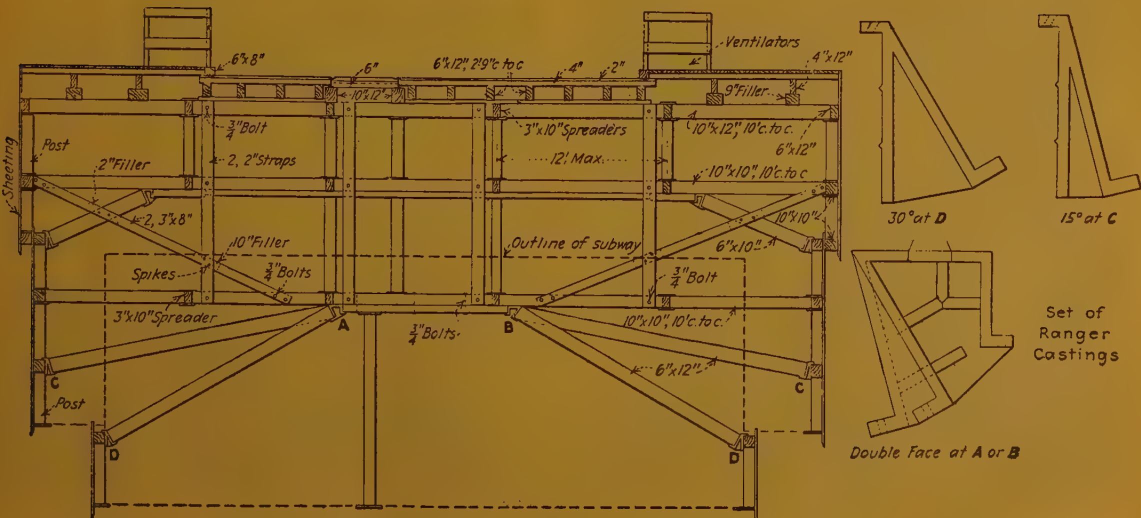


Fig. 14. — Arch bracing system on 14th Street line

virtually all cutting of timbers in the trench and 2. by providing for double rakers from the same point as *A* or *B*, figure 14. In practice this timbering system has demonstrated its capacity to hold the sides and the street traffic and its suitability for power-shovel work below it is manifest from the illustrations.

Excavation. — On the Flushing extension the cut was 53 feet wide at the portal and 70 feet wide at the dead-end Island station. In making the first cut about 12 feet deep to half street width, the shovels loaded into motor trucks on street grade alongside. With this cut excavated and timbered, the second cut was made alongside and the trucks stood on the decking. A view of this stage of the operation on the 14th Street line is shown by figure 16. In this first cut, shovels with standard booms were used but for the second cut under timbering, a specially-designed short-boom was substituted. One of these shovels is shown by figure 17; it is a straight electric shovel getting outside current.

On the Flushing line the shovel shown by figure 17 operated on 220 volts stepped down from the outside power line. It loaded into trains of 2-cubic yard side-dump cars hauled by gasoline locomotives to the portal and out onto the dump. Two tracks ran into the subway and a train was operated on each track. The material was mostly a clay-gravel mixture, very hard, with sand layers. Ground water was 15 feet above subgrade through most of the cut. It came in from a silty sand seam and had to be handled very carefully not to cause settlement. About 750 gallons per minute had to be pumped continuously. On the Flushing line the average excavation output on the opening cut was 300 cubic yards per shovel per 8 hours, with a peak of 700 cubic yards; under the decking an average of 200 cubic yards per 8 hours was maintained with a peak output of 400 cubic yards.

The shovels used on the 14th Street line were gasoline-electric machines, with long booms for the first cut and short gooseneck booms for the work under the timbering. When changed to work underground, however, the gasoline prime mover was cut out and current was taken from a cable installed for other purposes. With the gooseneck boom the shovel worked with a headroom of only 10 feet. The excavated material was taken out through shafts. The shaft structure above the street level is shown by figure 18.

On the two-track line the cut was 35 feet wide and on the three-track line it was 50 feet wide. The material was loam and sand with some gravel and boulders interspersed. The first cut was loaded directly into trucks as already described (fig. 16). Under the decking the shovels loaded into four-car trains hauled by gasoline locomotives. The cars held 2 cubic yards, dumped over the side, and at the shafts were unloaded into pits. At the shaft top an electric derrick operating a 1 1/4-yard clamshell lifted the material out of the bottom pit and put it into the truck-loading hopper (fig. 18). The shafts were about 1 500 feet apart. Excavation has averaged about 300 cubic yards per shovel per 8-hour day, with peaks of 600 cubic yards in the opening cut and of 500 cubic yards under the decking. For some 2 000 feet ground water was 5 feet above subgrade but it did not count heavily among the excavation obstacles.

Underpinning methods. — About 20 buildings on the Flushing extension and some 300 on the 14th Street line had to be underpinned. Familiar methods were followed, generally. Pits were sunk to below subgrade or to a point below a 1:1 slope projected from subgrade at the side of the structure, and concrete piers were built up to the old foundations. Where there was water the pits stopped at water level and from there pipe piles were forced to below sub-

Fig. 15. — Arch bracing and spoil track on Flushing extension.

Fig. 16. — Opening and timbering street half at a time, 14th Street line.

Fig. 17.
Short boom electric shovel on Flushing extension.

Fig 18. — Shaft head structure on 14th Street line.

Fig. 19. — Underpinning Elevated Railway column on 14th Street line.

grade, excavated and filled with concrete. These were the usual underpinning operations. For one building on the 14th Street line, there were special conditions and a different underpinning plan. The subway passes directly under a reinforced-concrete factory building with an ordinary « cement » floor on the ground and having interior columns.

Not to stop factory operations, the old cement floor will be taken up in sections and replaced with a reinforced-concrete slab. Excavation beneath will then be by hand, posts being placed under the concrete slab as the cut is opened up. Where there are building columns, underpinning pits will be sunk and timber bents placed to carry the columns until the subway is finished and they can be footed on the roof. About the same method was employed where several elevated railway columns came over the subway. A pit to below subgrade was sunk each side of the column footing in the line of the subway and a timber bent was set up in each pit. Spanning between these there was built the three-part (*A*, *B* and *C*) steel footing or grillage shown by fig. 19. Columns outside the subway were underpinned as were buildings. At one place the subway will go under the Long Island Railroad yards. Here also it is planned to sink pits, erect bents and carry the track on steel beams spanning between bents. After the tracks are underpinned it is proposed to excavate with a locomotive crane and clamshell.

Concreting methods. — For the Flushing extension an adequate mixing plant was set up on the nearby Flushing Creek so as to receive materials by barge. The cars and tracks used for excavation carried the concrete for the subway floors and lower 2 feet of the walls. Thereafter delivery was by motor truck over the decking from where the concrete is chuted to sides and roof.

On the 14th Street line a rather special outfit was erected. The concrete is mixed at a central plant and transported to the concreting point in 5-ton motor trucks. The cement shed is served by a railroad siding while the aggregate comes in scows and is transported to the storage piles at the plant by motor truck. A steel derrick with a 75-foot boom, operating a clamshell bucket, places the aggregate in the feeding hoppers.

The concreting plant consists of both sand and gravel hoppers feeding through smaller measuring hoppers into the mixers, the inundation system being used to measure the sand. The mixers are of 1-yard capacity, operated by electric motors, and are set back to back. A baffle plate above deflects the material into either one of the mixers, which can be operated together or separately. Two 18-inch belt conveyors 51 feet long rising on a 25° angle from both ends of the cement shed, carry the cement to the top of the building, discharging into a 12-inch spiral *flight conveyor*, which in turn discharges into the hopper directly above the mixers. The belt conveyor runs at a speed of 150 feet per minute while the *flight conveyor* makes 70 revolutions per minute. The bags are opened on the cement shed floor and the cement placed on the belt conveyor in batches. The capacity of the cement shed is about 3 000 bbl. Provision is made for heating the aggregate by steam both in the storage piles and in the feeding hopper. During very cold weather the water is also heated. Concrete is discharged from the mixer at a temperature of about 70°. The mixers discharge by gravity into 5-ton motor trucks. The longest concrete haul is 1 1/4 miles. The entire plant is operated by electric motors.

For all standard work, steel forms have been used for placing the plain concrete arches between the side wall columns and between the roof beams. The sidewall forms are poured in units and the whole unit form is moved by chain blocks and a carrier traveling on an I-beam fastened to the kneebraces on the sidewall columns. This I-beam is moved

ahead as work progresses. The roof forms are on steel travelers operating on temporary track placed on the subway floor. The traveler is in effect a movable platform with a small up-and-down adjustment by means of screw jacks. The forms themselves are on top of this platform and collapse onto it when moving them ahead.

Organization. — All construction is under the supervision of the Board of Transportation of the City of New York, Robert Ridgway, chief engineer. The technical personnel of the Oakdale Contracting Co. has already been stated. In the case of the 14th Street line there were two contract sections. This made it necessary to keep construction at a specified percentage stage of progress on each section independently of progress on the other section or on the line as a whole. This required a separate working organization on each section and a separate outfit with the exception of the mixing plant which served all the work. General management and overhead of course applied to both sections.

III

Construction of the third subway system for New York, is actively proceeding on 10.46 miles of line. This is the Eighth Avenue-Washington Heights line and the portion actually under contract extends from Greenwich Avenue (at about 7th Avenue and 11th Street) to 212th Street. Summarized, 22 contracts have been awarded to 15 contractors. The total amount of the contracts is $94 578 259; the largest amount to one contractor is $13 555 871, but three other firms have contracts adding up to over $10 000 000 each. Omitting the two small contracts aggregating $368 456, for special sections, the average contract amount is $4 710 490. The average contract price per mile of line is $9 041 899. This contract price includes all construction except track (rails, ties and ballast) and station finish.

Organisation directing construction. — Construction control of subway work is vested in the engineer staff of the Board of Transportation of the city of New York. More specifically it is in the hands of the construction division of the engineer staff; the intercourse, however, is at all times close with the design division. A deputy chief engineer is in general charge of construction and has under him a number of division engineers — at present five, of which three are in charge of line construction. The arrangement is flexible, other divisions can be created as may be necessary. There is a division office force, and then a number of sub-divisions each including about four contract sections. Either the number of sub-divisions or the number of contract sections in each can be increased.

This is the framework of organization — the engineer personnel is the flesh and integument. This is highly responsible down to and including the section engineers. The men on the sections are assumed capable of handling all the section problems and are held responsible for their handling. So also the sub-division men are held responsible for subdivision problems and the division men for division problems. The theory is to handle each problem where it lies and not carry it up the line of executive authority. It does not always work out, but it is striven for and obtained as far as the men will work together and are capable. Co-operation is held to be the spirit of the organization body. It is invoked not only between the engineers of the division, but between them and the contractors and in all ways throughout the directing personnel. To this end red tape is cut freely and the men are encouraged to negotiate and advise directly across the organization and not go too much up and down the ladder of official authority.

A policy that is stressed is co-operation with the contractors. With the engineers of the Board they are held to be the joint agents of the city for the construction of subways. Therefore in all their tasks they are given every advantage which the interests of the public considered broadly will permit. The theory behind the management of construction is non-interference to the greatest extent practicable with street travel and with the occupations in the buildings along the street. Nevertheless it is considered that there must be recognition of the facts that a great public improvement is being carried out; that, with all present surface and subsurface street structures, an under-street structure virtually the full street width and deeper than the ordinary bordering building foundations is being produced; that construction speed and economy call for power equipment and that this requires room and therefore street opening at the start to dig in and get under the surface, that, in brief, with all due deference to public convenience, there must be abnormal street conditions during subway construction.

It is in regulating the phases of construction wherein the public is directly affected, that engineering direction has its outstanding problem. The control of workmanship, materials and other items of fabricating structure is a task of importance corresponding to the magnitude of the subway operations but it all falls within customary good practices in engineering construction. It is with the plans for maintaining street surfaces, maintaining building services and safeguarding life and property that this review deals.

Maintaining street service. — Surface use of the street for travel is the first consideration. The requirements as stated in the specifications are :

« 47. In order to minimize interference with traffic and inconvenience to abutting property owners, during the construction of the railroad, on all parts of the work (except parts excavated by tunneling), the streets and sidewalks shall be substantially decked or covered over, and every precaution must be taken to keep traffic free from interruption.

« The street supporting system and street decking shall be substantially constructed of ample strength to safely carry the loads to which the surfaces, which it temporarily replaces, are subject. However, the contractor is privileged hereunder to restrict the use of the street decking to trucks and other vehicles weighing, including the load, not in excess of ten (10) tons carried on one axle and to limit the live load upon the decking to three hundred (300) pounds per square foot. In every case, however, where the loads are so restricted or limited by the contractor he shall at his own cost erect and maintain in the streets display signs visible at all times and take such other precautions as may be necessary to caution the public against placing excessive loads upon the street decking. Before the decking and street supporting system are placed, the plans for them shall be submitted to and shall be satisfactory to the engineer. In excavations covered by decking a means of illumination, satisfactory to the engineer, must be provided and maintained at all times, whether work is or is not in progress, so that the supports of the decking may at all times be readily inspected; and as a further means toward this inspection, galleries or walkways must be provided beneath the decking, so that inspection of its supports may readily be made when the excavation reaches such depth as, in the opinion of the engineer, to render such walkways necessary.

« 49. The street intersections, except where working shafts or ramps are located, shall be kept at all times open for traffic for their full width. Where the

decking is temporarily removed from any part of the street the opening shall be protected by suitable fencing and bridging. Generally the fences shall be not less than four (4) feet high and shall have two or three horizontal rails or as may be necessary to provide safety according to the local conditions.

« In all cases the contractor shall at all times at his own expense keep all the street crossings on the lines of the sidewalks in a clean and neat condition, bridging gutters and low places where water might collect.

« 50. The engineer will insist upon the close observance of the above requirements of this subdivision and no departure therefrom will be allowed, except upon the written permission of the engineer. »

These requirements are definite. Openings in the street are classed as temporary concessions granted as they are determined by the engineers to be necessary to the work. So also is the use of the streets for storage a temporary concession. The location and number of street shafts or ramps, of office and other buildings, of construction plant units depend likewise on the engineer's permission. Specifically, hindrance by construction operations to free surface use of the streets is not contemplated except as a temporary privilege determined by the engineer's judgment.

Subsurface street structures, as water and gas mains, sewers and conduits for electric cables are required to be maintained in service. The general clauses of the specifications governing this feature are as follows :

« 58. The contractor shall at all times, by suitable bridging or other supports, maintain and support in an entirely safe condition for the usual service and to the reasonable satisfaction of the owners, all surface, subsurface and overhead structures and all their appurtenances encountered or affected during the prosecution of his work; if the maintenance of such usual service makes it necessary, the contractor shall temporarily remove and relay or reconstruct any such surface, subsurface or overhead structure and shall restore the same or reconstruct the same in a new location prior to the completion of this contract. Also, in order that access may be had in emergencies to gates or valves on water, gas or other mains and to electric and other manholes, where such gates or valves and manholes are decked over, trap doors of a suitable size shall be provided in the decking. Whenever an electric manhole has been removed it shall be replaced by a temporary manhole, which shall be so constructed as to reasonably provide the usual facilities, and the cables shall be supported by temporary racks. Wherever possible and as determined by the engineer, reasonable, the ducts shall be supported and maintained but whenever it becomes necessary to remove the ducts from the cables, the cables shall be protected by a satisfactory boxing. Insulating coverings consisting of manure, hair felt or asbestos wrappings and boxings or other approved material and construction shall be provided and installed by the contractor for the protection of exposed water mains, and house service pipes as may be necessary to maintain the efficiency of the service within such pipes and to prevent freezing in water mains and house service pipes; to maintain the efficiency of such insulating material or construction it shall be protected by waterproofed wrappings or boxings or both, as necessary. All surface, subsurface and overhead structures and all their appurtenances and all surfaces of whatever character along the line of the work shall be protected from injury, and the contractor shall fully restore such surface, subsurface and overhead structures and all their appurtenances and all such surfaces to, and

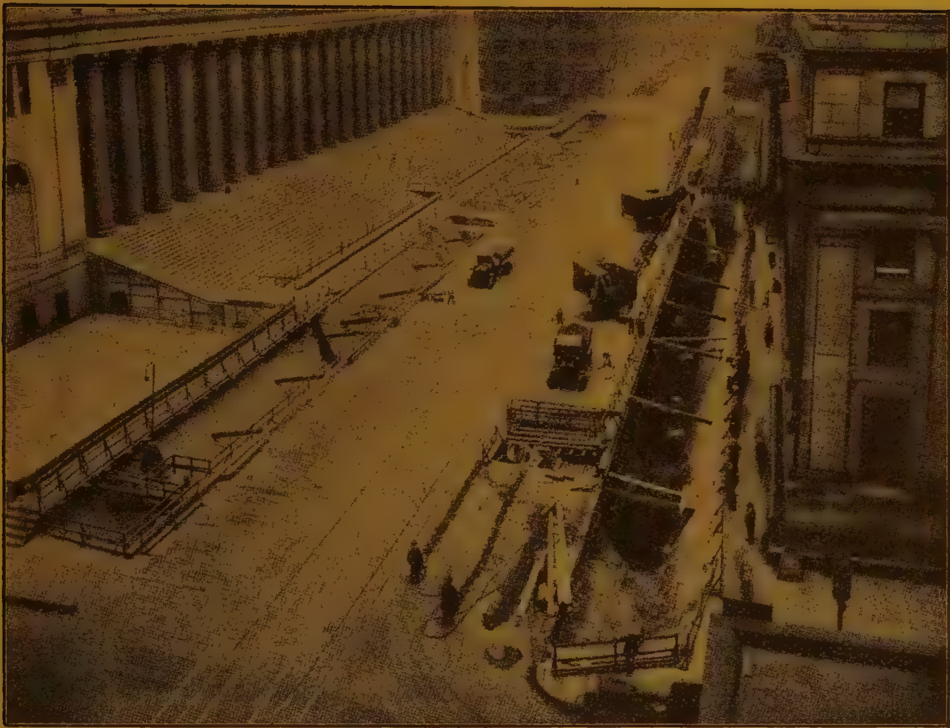


Fig. 20. — Eighth Avenue between Pennsylvania Station and General Post Office.

On Post Office side decking is completed to car tracks. On opposite (right hand) side see pavement being cut out, cranes and trucks for preliminary excavation and in distance patch of pavement removed and deck joists in place.

shall leave them in, as useful, safe, durable and good a condition as existed before construction was begun. »

These requirements apply only to maintenance; where the conduit, because of physical interference with the subway structure, has to be reconstructed it is held a part of the new structures and is provided for in the engineering plans and specifications.

Maintaining buildings. — Where excavation of subway may be carried to depths that may cause disturbance to the soil supporting adjacent buildings they are required to be underpinned as specifically named.

« 66. By underpinning is meant such method of construction as will transmit the foundation load directly through the underpinning structure to such lower level as is necessary to secure the buildings and which will relieve the adjacent ground and railroad structure from undue lateral pressures. The underpinning shall be designed to furnish a safe and permanent support for each independent building. To accomplish this result, the contractor shall use such methods of underpinning, pneumatic or otherwise, as special conditions may require and the engineer shall approve. »

Besides keeping structures intact it is required that the building services shall be maintained; entrances must be kept accessible and all the conveniences of doing business kept as undisturbed as practicable.

Guarding against hazards. — Potential hazard to the public in subway construction is naturally large. Openings in the street, handling materials and operating machinery in congested thoroughfares and blasting operations have great possibilities of danger unless well safeguarded. In the agreement the contractor takes the responsibility for safeguarding the public but general requirements are laid down by the engineers. Some of these are indicated in the quotations previously given. Others in respect to excavation and handling materials, embody the usual safeguards in respect to sheeting and bracing trenches, handling explosives and conducting blasting. City ordinances govern many of these operations and are too many to cite but all are required to be observed by the contractor. In brief the purpose is to reduce hazard to the public by every reasonable precaution. Causes of annoyance are eliminated as far as practicable :

« Decking of the streets, paving, or other surface work affecting, or affected by, street traffic, shall be prosecuted during such hours as will reduce such interference to a minimum. Night work shall be conducted, in accordance with the directions of the engineer, so that annoyance to occupants of abutting property shall be reduced to a minimum, and the engineer may, if in his judgment conditions so require, direct that night work be omitted.

« The contractor shall provide working machinery designed to operate with the least possible noise; hoists and compressor plants shall be electrically operated unless otherwise permitted and machinery by gearings shall be provided with a type of such gearings designed to reduce noise to a minimum. »

Conclusion. — To epitomize, in conducting the new subway work the service, safety and convenience of the public are recognized fully and are planned to be maintained in every practicable way. As far as practicable general requirements are specified but in a large way it has to be left to the judgment of the engineers how far maintenance and protection shall go and not hamper construction beyond any benefits to be gained.

IV

This fourth paper and the fifth are written by Lazarus White, President Spencer, White & Prentis, Engineers and Contractors, New York and preceded, in *Engineering News Record,* by the following Editorial note :

« The contract for section 3, route 78 (Eighth Avenue subway) 3 000 feet long, provided for the excavation of 200 000 cubic yards of which 20 000 yards are estimated to be rock fill and the remainder sand and gravel. The upper end is in filled ground and above ground water level; the lower end is in original sandy gravel 6 feet below ground water level. The original contract specified about 30 000 cubic yards of concreting and 3 300 tons of steelwork. The total contract price is about $4 900 000 and the contract time is 42 months.

« Eighth Avenue at this point is about 100 feet wide and is lined with five-story tenement houses with stores at sidewalk level. The subway averages about 60 feet in width, is standard four-track construction and there is a local station at 116th Street. There were about 100 elevated railway columns to be underpinned, these columns being mostly on the side-walks just inside the curb line. »

* * *

The contractors for this section of the Eighth Avenue subway felt that the changing economic situation and the developments of machinery since the construction of the dual subways, completed about 1920, necessitated different methods. During this interval the excavation of cellars, basements and foundations of large buildings had undergone a revolution. Derricks, skips, and horse-drawn trucks had been superseded by power shovels, motor trucks and ramps. Particularly, there had been a great development in the use of small crawler traction shovels, and a wonderful improvement in motor dump trucks. These trucks though weighing about six tons themselves can readily carry an additional load of about 5 cubic yards of excavation up a 15 % grade. The flexibility of crawler shovel and motor truck outfits enables excavators to make phenomenal records in the removal of excavation from difficult and cramped locations.

Construction plan. — Realizing that steam, or gasoline shovels would be objectionable below ground, the contractors investigated the relative merits of shovels operated by air and electricity. The electric shovel was finally chosen because of its superior economy and flexibility. The section, being 3 000 feet long, was divided into four parts, or headings, by two ramps at 114th Street and at 120th Street. The ramps, were constructed on a grade of about 15 % and at right angles to the prism of the subway, laid out so as to intersect the subway at subgrade. These two ramps were found to be entirely adequate for the work and useful in all stages of the construction. From each of them about 100 000 cubic yards of excavation were removed in the period of six months, and a great deal of the structural materials of the subway such as concrete, steel, ducts, and timbers, were delivered by trucks through them. These ramps were considered to be less objectionable to the neighborhood than the old style of overhead gantries with their derricks, muck bins, etc.

After the use of the ramps was decided upon, the problem of supporting the street surface, trolley tracks, etc., in such a manner as to allow the operation of the shovels, trucks, etc., remained. The solution of this problem was about as difficult as could be encountered, as it was necessary to support two underground trolley tracks, numerous electrical subways for telephone and power cables, pipe lines, street and sidewalks in such a manner as to allow underpinning of the elevated railway. It was also considered essential for reasons of economy that the four tracks be excavated in one operation.

Supporting street structures. — Referring to figure 21, it will be seen that the main supporting members are four longitudinal I-beams laid parallel to the track and to the curb. These beams were framed in pairs by means of 6 × 12-inch cross timbers resting on the lower flanges of the beams and by tie bolts at intervals. Upon this framework the 6-inch deck is laid. The beams were laid as close as possible to the street surface so as not to interfere with the sub-surface structures below. The beams were lightly spliced longitudinally so as to hold their alignment. The problem of supporting the two trolley tracks and allowing sufficient space for the operation of the electric shovels was solved by placing transverse beams in a heading preceding the shovel. These beams were placed at intervals of 10 feet and were posted to subgrade. These posts were fastened to the beams by means of angles so that the shovels could not readily displace them. The outer beams were directly supported by posts at 10-foot intervals (figs. 21 and 22).

Excavation methods. — In advance of the main excavation, largely to facilitate the underpinning of the elevated railroad columns, a trench was dug between

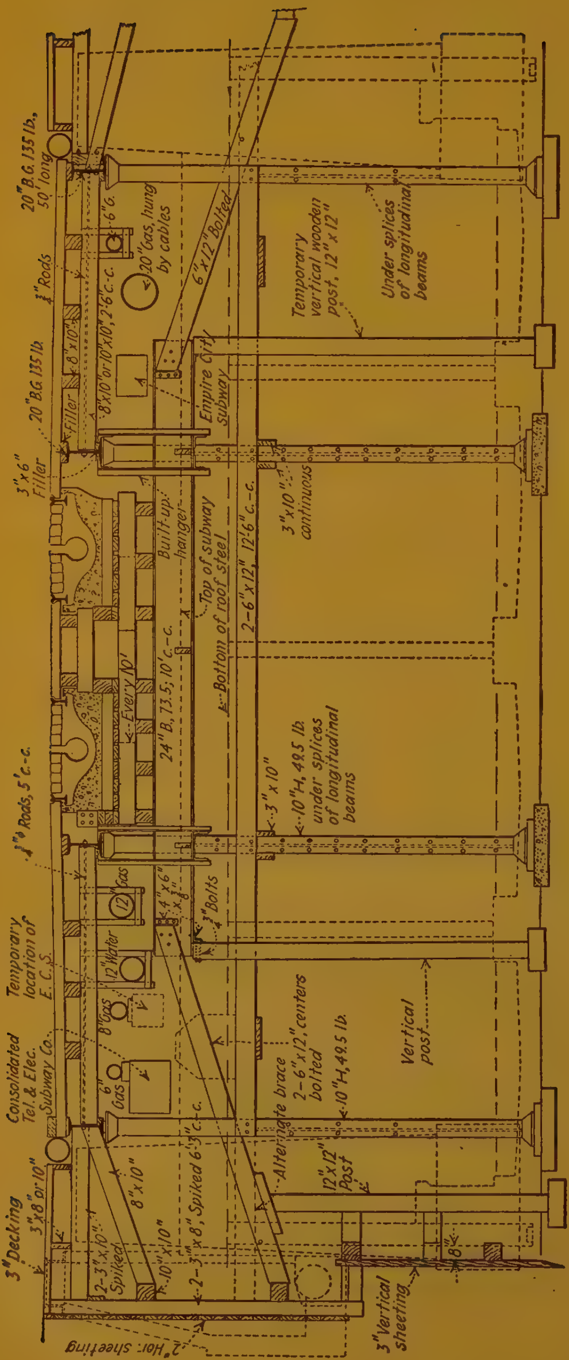


Fig. 21. — Typical street decking and supports.

the exterior beam and the outside of the subway. This trench was usually carried to a depth of about 12 feet, except at the elevated columns where it was carried to the depth of the base of the columns. The exterior sheeting of this trench was supported by braces directly to the outer beams, the upper brace horizontal and the lower one at an incline. The deck was made rigid by blocking between the inner beam and the concrete of the trolley tracks. The upper braces served a very important function, as they held the trolley tracks in line and enabled the excavation to proceed to a considerable depth without additional bracing. The shovel operating at subgrade excavated a complete section with the exception of a berm intentionally left at each side to decrease the amount of sheeting necessary. The berm was about 12 feet wide by 12 feet high. The ends of the transverse beams supporting the trolley tracks were braced to a lower ranger by an inclined strut consisting of two 6 × 12-inch timbers bolted together and to the end of the beam. Two angles attached to the beam served as abutments for the brace.

Four shovels (fig. 22) were in operation for two shifts at the maximum and the maximum month's work was about 30 000 cubic yards, about thirty trucks being employed. The excavation of the cut was disposed of at Riverside Drive north of 104th Street. When the headings met, the berm remaining at each side was removed by the shovels or by portable belt conveyors electrically operated. The shovels were found to be best for rock fill and the conveyors for sand and gravel. As the berm was removed, additional sheeting was placed to subgrade, generally vertical sheeting, supported by rangers which were in turn supported by short struts extending to an intermediate post below the main brace. It was found that when the excavation was extended to subgrade the pressure at the bottom was not noticeable but that

Fig. 22. — Timbering and cut at subgrade.

Note space for power shovel and trucks. Temporary steel posts shown in figure 21 not yet placed. Note hangers for transverse beams.

there was a considerable increase of pressure at the top braces, particularly at the uppermost brace. This was as expected, the bracing being designed for a computed total pressure obtained from observation by engineers experienced in this class of work. This method of timbering not only conformed to experience but allowed freedom in the operation of the subway construction. Had the ordinary theories and methods of timbering been followed, the operation of the shovels and trucks would have been seriously hampered, if not impossible. Also the ease with which long and heavy H-beams can be secured enables the contractor to operate with a freedom which could not be realized on the old subways.

Concreting plant. — Another feature of this work to be noted was the use of a central concrete mixing plant. This plant is shown in figure 23. The plant follows

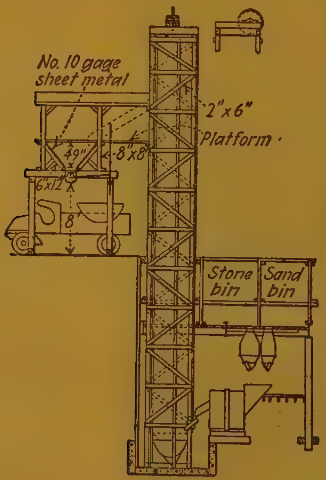


Fig. 23. — Arrangement of concrete mixing plant.

road building practice; it is completely enclosed and enables the concreting work to proceed in all weathers. The bins are heated by steam obtained from a boiler with an oil burner. This oil burner operates very satisfactorily. The concrete was transported by means of three trucks with roll-over bodies of about 1 1/2 cubic yard capacity. It may be noted that on the worst days of the past winter when about one foot of snow fell 200 batches of concrete were placed in the subway. The concrete plant is equipped with Butler proportioning hoppers, which greatly facilitate the work and give an accurate mix. The forms used were mainly Blaw-Knox forms of the type usually used in subway construction.

The shovels used on this work were Bucyrus 20-B model. These shovels are operated by two motors, one the main motor on the engine, and the other the crowding motor on the boom, the boom being specially short and of cast steel. This shovel is of a type convertible into a gasoline shovel. These shovels were also operated as cranes, being equipped with special booms for this purpose. They will work freely in a clear space of about 30 feet wide by 13 feet high. A small crawler crane was also found to be very useful on this work, both in the excavation trenches and in the erection of steel below the deck.

A central compressor plant was installed at one end of the work and an air line laid on a bypass trestle. Indeed this contract was noteworthy for the amount of overhead gas bypassing necessary. The pipes were installed on overhead trestles and ranged in size from 30 to 4 inches. It was found that plain end pipes with dresser couplings made a very efficient line. Several thousand feet of 20-inch line was laid on trestle within the period of a few weeks, and passed the first test without the retightening of a single bolt.

V

An exceptional underpinning problem existed on Eighth Avenue, from 111th to 121st Streets, where for ten blocks the Ninth Avenue elevated railway, a 5-story structure, extended directly over the four-track subway line. Here the subway cut

was 25 feet deep and over 60 feet wide in rock fill, sand and gravel. The task was to hold the elevated structure during the construction of the subway and then transfer its support to the roof of the completed underground structure. Because of the height and age of the elevated structure a tedious operation was promised. However, to the credit of Heyman & Goodman, Inc., contractors for this section, it may be said after only one year of work the entire underpinning is completed, nearly all the excavation has been removed and several blocks of subway structure are completed including the transfer of the columns of the elevated to the roof of the subway. In money value about 70 % of the work has been completed in about one-quarter of the allotted time.

Elevated structure. — About fifty years ago, the Ninth Avenue elevated road was extended northward into Harlem. As Ninth, or Columbus, Avenue terminated at 110th Street, the railroad was forced into a reverse curve around Morningside Park, at this point leaving a hill to the south and traversing the low lying Harlem plain to the north. The structure has a height exceeding that of the adjoining five-story building and for a considerable time was one of the sights of the city of New York, considered by engineers to be an outstanding feat of steel construction. It consists of pin-connected trusses and Phoenix columns. The structure subsequent to its erection was stiffened by additional cross bracing. The present level of Eighth Avenue north of 110th Street is about 25 feet above that of the original plane, and at 120th Street the grades meet. In most cases the original builders were very conscientious in securing a good foundation, digging down to firm material. At 112th Street it was necessary to penetrate about 6 feet of pond muck to secure a good footing. The brick piers supporting the structure were founded on layers of rough concrete of varying thickness, the brickwork ranging in height from 15 to 30 feet and having an area at the base of about 100 square feet. The column was cemented into a large base casting with a « rust » joint, the casting being bolted down with four large bolts extended through a bonding stone about half way down the pier. The brickwork was laid in a cement said to be an imported portland and was found to be in excellent condition, as were also the wrought-iron bolts.

Underpinning. — In previous work of underpinning elevated railway columns in New York the track girders have been supported by wooden towers from the street surface or else plate girders have been directly attached to the columns, enabling the excavation to be carried on immediately below the columns and the original column base to be removed. Here there were serious objections to either of the methods mentioned. The wooden towers would have had to be of great height and exposed to danger of fire and collision. For supporting plate girders it would have been very difficult to secure proper connections to the Phoenix columns. It was therefore decided to underpin the supporting brick piers from below and use only permanent materials in this work, that is, to underpin the columns as if the underpinning was to remain permanently in place, even though it might be removed within a year.

Referring to figure 24, it will be seen that the main supporting members are six concrete-filled steel tubes 16 inches in diameter and about 3/8 inch thick. Each tube was placed within a horizontally sheeted pit and jacked down hydraulically to about 5 feet below subgrade, and then filled with concrete and by the pretest method tested to about 30 % over the working load it was figured to carry. In this method two hydraulic rams are placed upon a steel plate at the top of the pile and pressure is applied by a hand operated pump connected to the rams by flex-

ible copper tubing. As soon as the pile bears its test load without settlement an I-beam is cut to fit the space between the cap and the bottom of the footing and is securely wedged in place, so that upon removal of the jacks the rebound of the pile is held to 1/32 inch. A detail of the pretest wedging is shown by figure 25.

The operations described complete the underpinning of the columns as far as necessary to enable the excavation to be carried to the designed subgrade of the subway, but do not make any provision for the transfer of the elevated column to the roof of the completed subway. This was accomplished by inserting four needle beams directly into the brickwork of the pier. First a central slot was cut about 30 inches below the base of the casting and of a dimension just sufficient to allow the placing of the two central needle beams shown in figure 26. These beams were 16 ft. 6 in. long and weighed from 90 to 120 lb. per foot. The cutting of the central hole, a delicate operation, was accomplished by jackhammer drills clamped to a frame attached to the column base. The holes were drilled through from one side. After the holes were drilled they were broached out by air-operated concrete breakers. When the central beams were grouted in, slots, by similar methods, were cut on each side of the pier and a third and fourth beam placed. It was required that these needle beams be placed before any excavation was made beneath the piers.

After the operations described were completed, the excavation for the subway was completed for the full width and depth, the material surrounding the piers and the underpinning below the piers being taken out with the main excavation. The material encountered at subgrade was mainly sand and gravel. After the concrete invert was placed steel bents were erected not on the customary 5-foot spacing but at spacing to accommodate the needle beams in the brick piers in the manner as shown in figure 26. The girders supporting the needle beams and the beams themselves were field drilled and temporarily bolted together, after which shims were placed filling the gap between them.

The next step was to expose and cut anchor bolts. These anchor bolts were cut by an acetylene torch, and heated and bent at right angles to form a hook. The original brickwork remaining was then drilled so as to establish a plane of cleavage. Special steel castings were inserted between the flanges of the I-beam and by means of four hydraulic jacks shown in figure 27 the column was raised about 3/8 inch and by aid also of plugs and feathers the pier was split at the drill holes as planned. The apparatus worked perfectly, and the operation of raising the column, inserting the necessary shims between the grillage beams and the supporting girders was often done in about 15 minutes. This operation not only tested all the supporting members but also the footings of the steel subway columns designed to carry the load of the elevated column. These footings were ordinary grillage footings.

To secure a good footing in the neighborhood of 111th and 112th Streets, it was necessary to go several feet below the main subgrade of the subway to the bottom of the original pond, a firm mixture of sand and gravel. This is about the level of the original elevated column footings. It was not necessary to interrupt trains during any of the transfers. By means of gages attached to the hydraulic apparatus the actual load of the columns was measured. This was found to be about 60 tons, but the dead load of the original pier was about as much. Where columns were not to be supported on the roof of the subway no needle beams were inserted, and it was not necessary to go through any transfer operations. At St. Nicholas Avenue, the spans are large and the loads on the columns are correspondingly greater; at some eight underpinning piles were used.

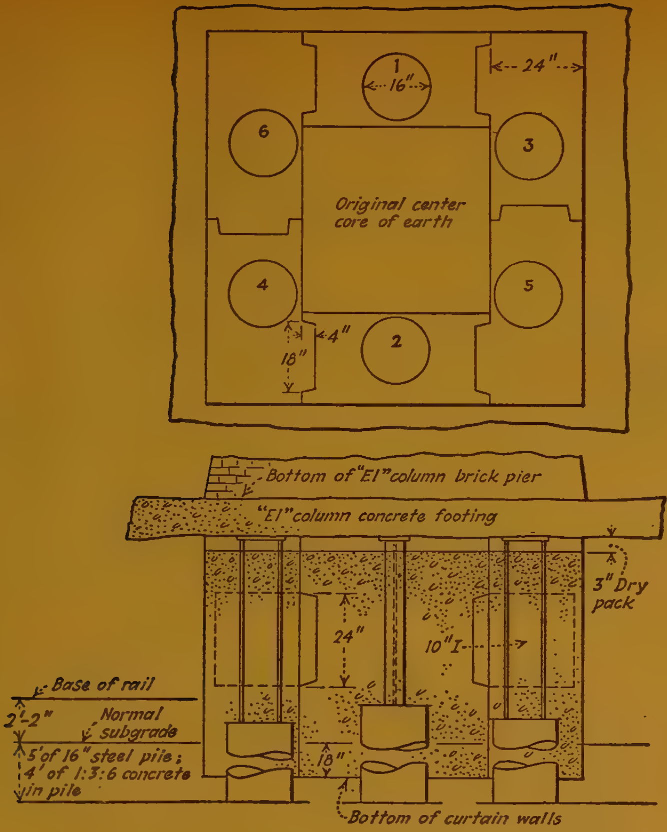


Fig. 24. — Typical column underpinning diagram.

Brick pier and footing held up by inserting 16-inch piles, one at a time in order numbered, underneath.
Piles pretested to 30 % over their working loads.

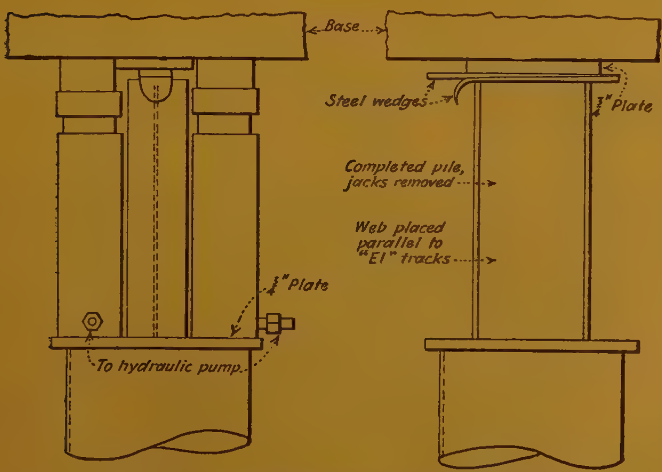


Fig. 25. — Arrangement for pretest wedging.

When gage on hydraulic jacks shows load 50 % in excess of working load steel wedges are inserted on top of I-beams cut to fit and are driven until rebound of pile is prevented.

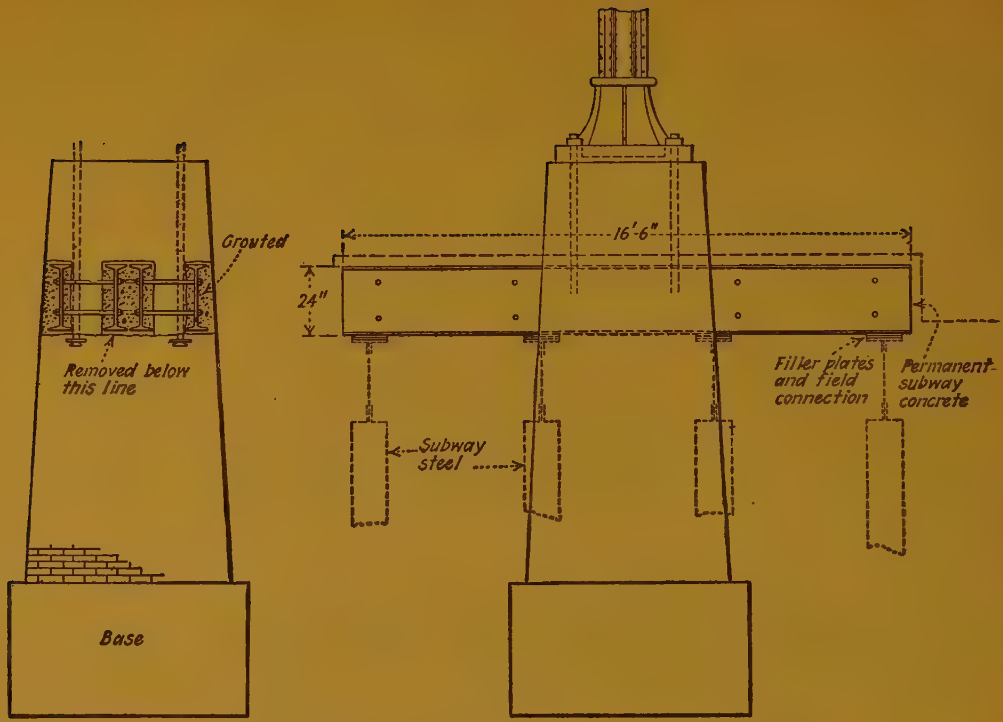


Fig. 26. — Needle beams transfer column load to subway.

These beams are inserted after pier is underpinned but before it is laid bare by excavation.

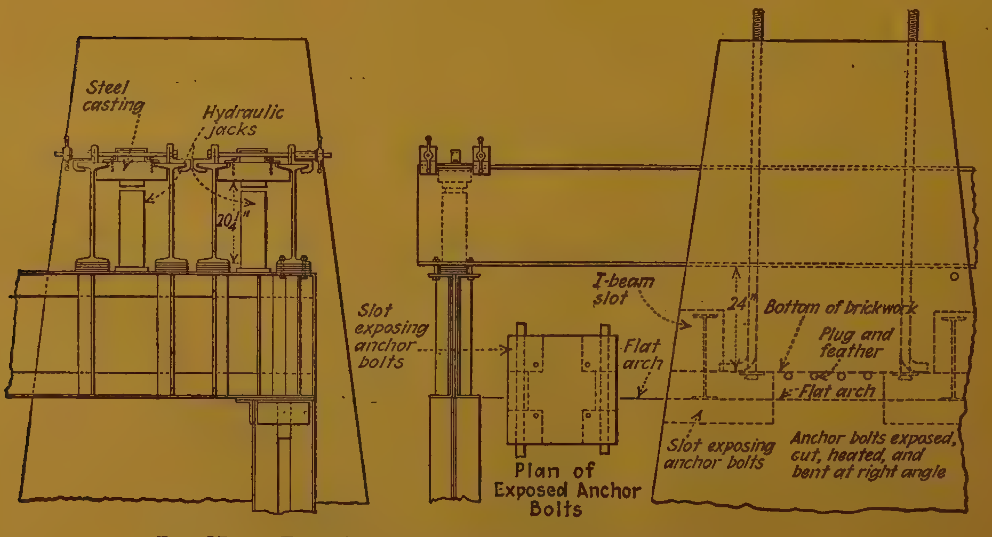


Fig. 27. — Transferring load from pier to subway structure.

After the transfer operations were completed about 2 feet of brickwork below the plane of cleavage were cut out by concrete breakers and the remainder of the old brick pier was drilled and blasted, using light charges of powder; then two partial bents of steel were erected and the sidewall concreted, the last operation being the concreting of the roof and the grouting of the space between what remained of the original pier and the roof of the subway.

During the transfer operations it was noted that there were only very slight deflections of the grillage beams and supporting girders, indicating ample factors of safety in the supporting steel. Accurate elevations were kept on the elevated columns during all stages of the underpinning and transfer operations. During the underpinning operations only slight settlements were noted, the average being less than 1/4 inch. Final elevations of columns were 1/8 inch above original grades.

It will be noted that the main effort of these underpinning operations was to secure maximum safety, using a permanent construction for what is described in the contract as a « temporary support of the elevated railroad ». Also that by the method of transfer used any settlements occurring during the underpinning operations could be very easily corrected, and that unless these settlements were sufficient to introduce undue stresses in the structure they were of no consequence. By 1 April 1926, all the columns were underpinned, about 100 in all, and several blocks of the elevated railway are permanently transferred to the subway roof without the slightest observable damage to the structure.

VI

By Leo M. CHARM,

OF ENGINEERING STAFF, ROSOFF SUBWAY CONSTRUCTION COMPANY, INCORPORATED, NEW YORK.

« Section 3A of Route 78 of the Eighth Avenue-Washington Heights line on St. Nicholas Avenue, between 122nd and 132nd Streets, is 2 640 feet long. The railway is standard one-level four-track line, except at the north end where there are two additional tracks for storage. There is an express station at 125th Street. On the east side of the street, which is 100 feet between building lines, there are brick buildings, generally four to six stories, the full length of the section. Similar buildings border the west side of the street from 122nd to 128th Streets. North of 128th Street to 132nd Street on the west is St. Nicholas Park rising in a rocky bluff from street level. The 125th Street station has a mezzanine floor 660 × 75 to 85 feet and two island platforms 660 feet long. At 124th Street a sewer system of three 48-inch cast-iron pipes passes under and is a part of the contract structures.

« Construction on this section was begun 14 March 1925, and the work is now 85 % complete (Editorial note, *Engineering News Record.*) »

* * *

Power-shovel excavation with motor-truck haulage of spoil directly from the cut was laid down as an essential of the construction plan for Section 3A, Route 78 of the third subway system. This in turn called for a timbering system for the cut which would give clear space underneath for shovel and truck operation. Incidentally it dictated ramps instead of shafts for raising the spoil from the excavation.

Briefly the cut required for placing the subway structure was 2 640 feet long, from 60 to 90 feet wide and from 25 to 35 feet deep. These dimensions carried the excavation well up to the buildings generally and in places under them, and always to a depth well below the building foundations. For about 1 800 feet of the north end of the section rock is at the street surface on the west side and slopes downward to about half the

Fig. 28. — Bypassing 36-inch and 24-inch gas pipes over St. Nicholas Avenue at 124th Street.

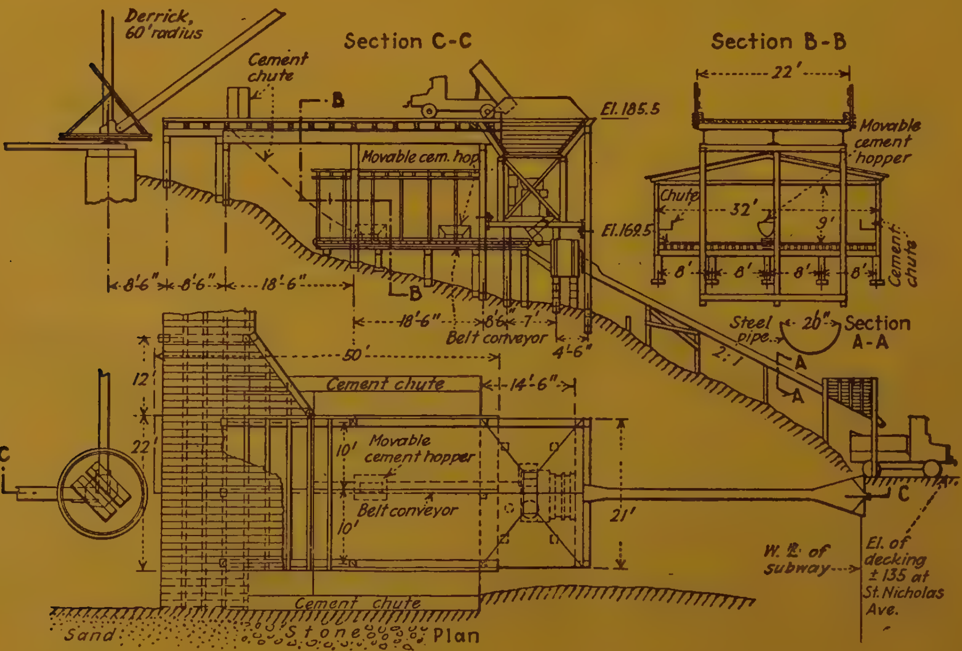


Fig. 30. — Concrete mixing plant on New York subway job.

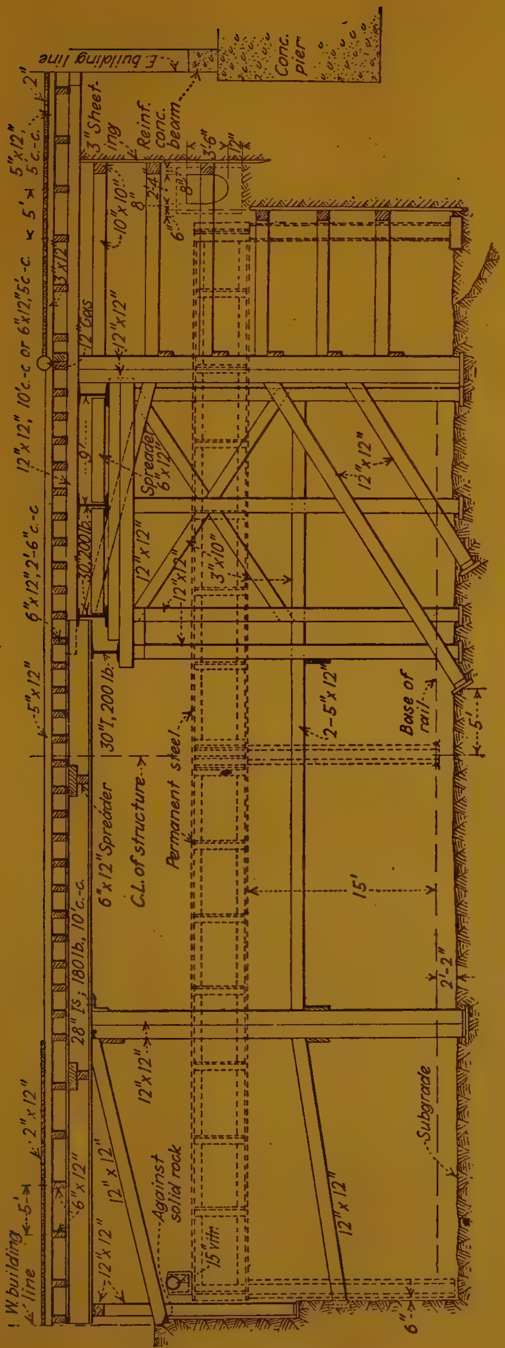


Fig. 29. — Timbering in cut one side earth and one side rock.

depth of the cut on the east side of the street. The overburden is earth and loose rock. South of this section the cut is in earth, loose rock, rock fill and rock. The excavation quantities are 120 000 cubic yards solid rock and 150 000 cubic yards of other materials. The subway structure called for 35 000 cubic yards of concrete and 5 000 tons of steelwork.

Construction is planned to follow this sequence : 1. Bypassing gas mains; 2. underpinning buildings; 3. opening and covering street half at a time; 4. constructing ramps; 5. excavation; 6. concreting track slab and column footing; 7. erecting steel; 8. concreting walls; 9. roof concreting after load of street structures is transmitted to permanent steel; 10. waterproofing, protective concreting and backfilling; 11. restoring sub-surface street services; 12. repaving. The contract was signed 5 March and work was formally begun 14 March, 1925.

Bypassing and underpinning. — Occupation by the subway structure of virtually all of the street made necessary the care of all street structures and services. All buildings had to be underpinned; stoops along both sides of the avenue had to be removed or supported; gas and water pipes had to be relocated; existing sewers replaced by sewer flumes, and electric cables and pneumatic tubes carried. Much of the temporary conduit work was handled in connection with the timbering work and is there indicated. Gas main bypassing was, however, accomplished by surface or overhead lines. This overhead gas bypass work involved some unique structures as indicated by figure 1. North of 128th Street three gas mains were replaced by one 12-inch gutter pipe along the east curb line of St. Nicholas Avenue. Crossing the avenue were a 48-inch overhead crossing at 127th Street; one 20-inch and one 30-inch overhead crossing at 126th Street; one 12-inch and one 20-inch overhead cross-

ing at 125th Street; one 24-inch and one 36-inch overhead crossing at 124th Street (fig. 28), and at 123rd Street, one 12-inch, one 24-inch and one 36-inch overhead crossing.

As stated, all buildings had to be underpinned. Few of them were of great height but, by the same token, their foundations were not particularly deep or stable. Methods varied with conditions. Generally concrete piers, spanned between by reinforced-concrete beams carrying the walls, were used. In other cases steel cylinders were jacked down and filled with concrete. Where later the foundation load had to be transferred to the subway steel, steel-beam needles were put through the piers to take seat finally on the roof beams of the subway. In general there were no extra-hazardous underpinning tasks nor were special methods required but the standard methods used received unusual care.

Decking and timbering cut. — Timbering and excavation are supplementary and simultaneous operations in large measure but separate description makes them more easily understood. At the outset, the avenue was decked its full width. A power shovel removed the pavement for one-half the street width and excavated deep enough to allow the 30-inch I-beams and 5 × 12-inch decking supported by 12 × 12-inch posts to be placed. When one-half of the avenue was covered and available for traffic, the other half was excavated and decked similarly. With the street decked full width, the posts were carried down and the timbering and bracing were developed always with the object of bridging the cut and so far as possible keeping a clear space underneath for power shovels and trucks and for construction operations. As the trench was in places 90 feet wide and over 30 feet deep this timbering process was a major one.

A number of types of timbering were used to meet varying situations. While the basic design in all cases was a wide-open structure of longitudinal 30-inch 200 lb. I-beams carrying the timber deck and in turn supported by bents of posts and caps, the requirement had always to be met that the timbering could not interfere with the placement of permanent structure. Again there were varying demands for side support of the cut. How these conditions influenced the timbering design, and yet satisfied the essential requirement of providing room for power shovel and motor truck excavation, are indicated by the following examples of timbering plans.

North of 128th Street where the subway borders St. Nicholas Park one-half only of the street was timbered, the other half being taken out in open cut. The half-width timbering holds closely to the basic design described. South of 128th Street the full width of the street between building lines was decked, the east side of the cut being in earth while the west side was in rock. Figure 29 shows the timbering system. This arrangement gave, first, a stiff support for the east side of the cut in earth 30 feet deep and close to the building line, and second, for the west side where the cut was in rock a particularly wide open space for excavating operations. In the section of the 125th Street station between 124th and 126th Streets there was no rock, the material being sandy loam and gravel; the depth of excavation was about 34 feet and the width about 95 feet, the subgrade being 12 feet below ground water level. On account of these conditions and the proximity of buildings on both sides of the street to the excavation lines it was necessary to use heavy bracing to support the sides. For the section south of 124th Street a decking and bracing system was employed, a feature of which is that the floor and steel of the two central bents were first put in and held the bracing and sheeting for excavating for the two outside tracks.

Excavation. — Virtually all excavation is by power shovel loading directly into trucks which climb ramps to the street and go on to the dumps. Ramps were used to raise the greater part of the excavation but in one or two cases the shaft method met the conditions better and was used. An example was the six-track section north of 128th Street; the excavation for the east track on account of its being very close to buildings was left until the steel for the other tracks was in place and could be used to brace against when sheeting the side of the cut close to the building line. There were three ramps. Two of these were at 132nd Street and at 129th Street and handled the excavation north of the 125th Street station and some of the station excavation. The third ramp at 123rd Street handled the remainder of the excavation.

Blasting was required for about one-half of the excavation. Generally a center cut was made and widened. To trim the sides, line holes 6 to 12 inches apart were fired with small charges. The chief trouble came from slides. These were handled in various ways but generally by buttresses of rock left until the steelwork was in place to hold the cut wall and then taken out. Ground water offered no problem beyond ordinary pumping methods. Compressed air was used for drilling, paving breakers, pumping, steel riveting and other pneumatic tools and was provided by a power plant which consisted of two 250-H. P. motor-driven compressors with a combined capacity of 2 600 cubic feet of free air per minute. The pressure at the compressor was 110 lb.

Steel erection and concreting. — First the floor and column footings were concreted. Steel erection, center wall and side-wall concreting followed in order. Steel forms were used for center wall and for the side walls above the duct benches. For the roof jack arch forms of steel carried by travelers were used. Waterproofing, protective concreting, backfilling and street restoration follow in sequence.

The concrete was mixed at a central plant at 128th Street and St. Nicholas Avenue where a side hill provided an admirable site for gravity handling of concrete materials and mixed concrete. The design of the plant is shown by figure 30. All materials come in by truck at street level on the hill top. Sand and stone are dumped into the mixer bins or into stock piles having capacities of 3 000 cubic yards of stone and 2 000 cubic yards of sand. The cement in bags is unloaded from trucks into chutes leading to the cement house floor. From the mixer bins stone is measured into the mixer charging hopper and sand into an inundator and then into the charging hopper. Cement is measured into a hopper over a belt conveyor which runs to the charging hopper. From the mixer a chute runs to the concrete hopper trucks at street level deliver concrete to the work.

[621 .13 & 669 .1]

Metallurgy of locomotive iron and steel,

By Fred WILLIAMS.

ASSISTANT ENGINEER, CANADIAN NATIONAL RAILWAYS, MONTREAL.

Figs. 1 to 18, pp. 769 to 771.

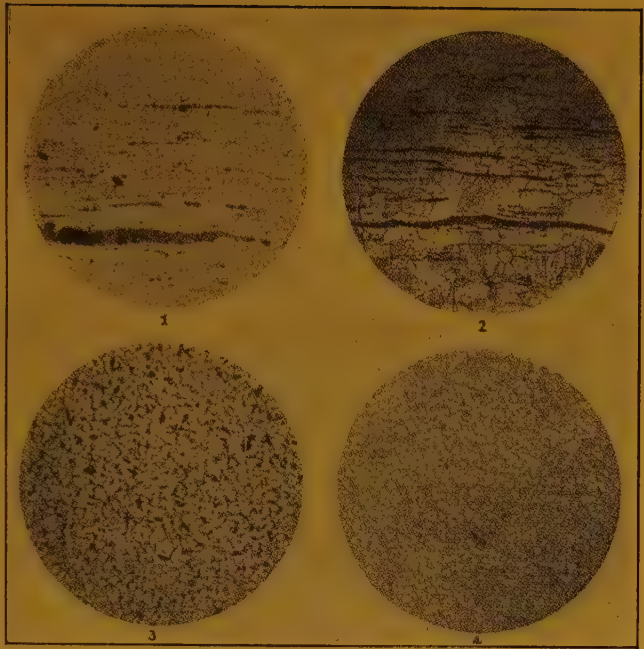
(*Railway Mechanical Engineer.*)

At infrequent intervals the mechanical department of a railroad is faced with the problem of trying to determine the cause of an epidemic of broken staybolts, crown bolts, springs, or other parts. The first step generally taken when making such an investigation, is to determine that the design is correct and that the part has been properly applied. If this investigation does not reveal the trouble, then it is necessary to examine in the laboratory by means of the microscope the structure and physical properties of materials from which the various parts are made. The photomicrographs often reveal some surprising conditions. They point particularly to the importance of proper heat treatment of anything but mild carbon steel.

The photomicrographs shown in figures 1 and 2 show the impregnation of slag in wrought iron. These streaks or slivers of slag are what cause the so-called « fiber » in this material. This slag is necessarily brittle and when the iron is bent, it will naturally disintegrate and allow the iron to come apart and give the appearance of a rope-like structure in the bar. Slag in iron as a virtue is very much misrepresented. Some people claim that these streaks of slag will stop progressive fracture or, at least, delay it or make a ragged fracture when the iron breaks. An appeal to reason in scanning the photographs shown in figures 1 and 2 cannot help but show that a progressive fracture would be caused internally and also in the surface by these slag particles and streaks. In spite of these so-called fibrous qualities of wrought iron, experience has been that staybolts made of this material will generally break off short. A comparison of the crystallographic structure shown in figure 2 with those shown in figures 3 and 4, will show that wrought iron has a cristalline structure similar to low carbon steel.

Figure 3 shows the uniformity of structure in low carbon steel. Its low carbon will give uniform structure and it does not require heat treatment. Therefore, it can be used for engine bolts in preference to wrought iron. In fact, it can be headed much more readily than wrought iron, as it will not split in heading. Neither will it become brittle under the head, which is the case in bolts manufactured from higher carbon steel when not subjected to subsequent heat treatment. Figure 4 shows the clean character of very low carbon steel and also the similarity in the crystalline structure to the wrought iron shown in figures 1 and 2. A comparison of the physical properties of figures 1 and 2 with figures 3 and 4, will show their adaptability to their various purposes.

Figures 5 and 6 show how essential it is to heat treat carbon or alloy steels



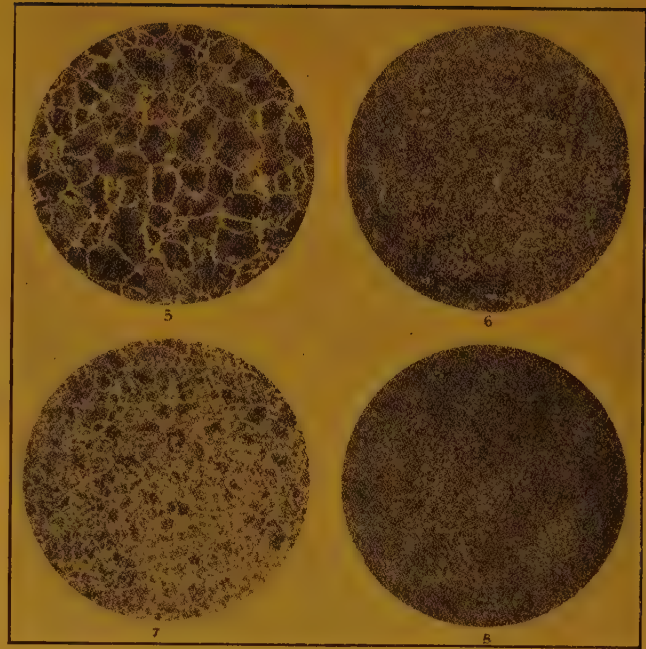


Fig. 1. — Wrought iron, unetched.

T. S., 47 750 lb.; Elong., 36.5 %;
El. L., 35 000 lb.; R. A. 57.0 %;
Brinell, 90; Mag., 100.

Fig. 2. — Wrought iron, etched.

Mag. 100.

Fig. 3. — Low carbon steel.

T. S., 63 200 lb.; Elong., 37.5 %;
El. L., 43 300 lb.; R. A., 69.0 %;
Brinell, 112; Mag., 100.

Fig. 4. — Very low carbon steel.

T. S., 52 200 lb.; Elong., 43 %;
El. L., 39 650 lb.; R. A., 79 %;
Brinell, 99; Mag., 100.

Fig. 5. — Carbon steel 0.40, as rolled.

T. S., 98 955 lb.; Elong., 24.5 %;
El. L., 67 250 lb.; R. A., 53.0 %;
Brinell, 196; Mag., 100.

Fig. 6. — Carbon steel 0.40, heat treated.

T. S., 135 800 lb.; Elong., 20.0 %;
El. L., 103 450 lb.; R. A., 55.5 %;
Brinell, 311; Mag., 100.
Quenched from 1 500° F. in water;
drawn at 800° F.

Fig. 7. — Carbon 0.30, 1.25 ni. ch., as rolled.

T. S., 110 700 lb.; Elong., 22.5 %;
El. L., 88 810 lb.; R. A., 59.0 %;
Brinell, 222; Mag., 100.

Fig. 8. — Carbon 0.30, 1.25 ni. ch., heat treated.

T. S., 173 300 lb.; Elong., 15.5 %;
El. L., 167 900 lb.; R. A., 54.5 %;
Brinell, 345; Mag. 100.
Quenched from 1 475° F. in water;
drawn at 800° F.

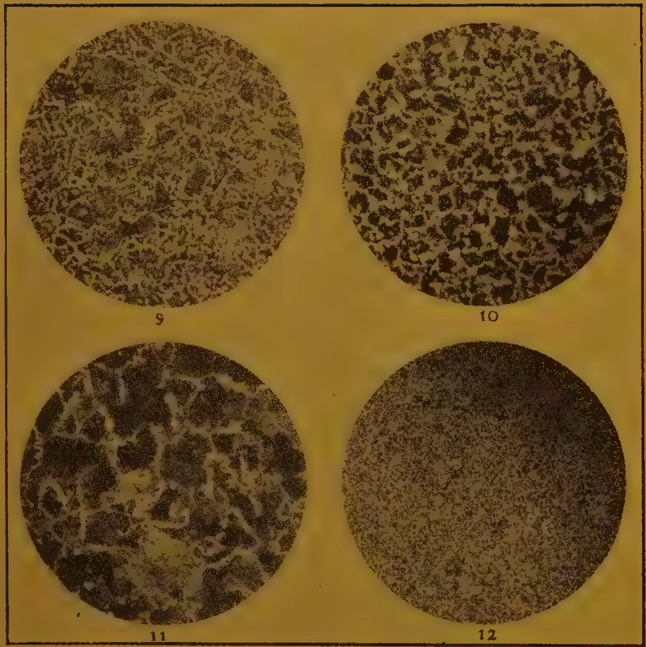


Fig. 9. — Carbon steel 0.40, as forged.

T. S., 90 300 lb.; Elong., 23.5 %; El. L., 51 600 lb.; R. A., 44.0 %; Brinell, 158; Mag., 100.

Fig. 10. — Carbon steel 0.40, annealed 1 600° F.

T. S., 89 300 lb.; Elong., 28 %; El. L., 49 500 lb.; R. A., 50 %; Brinell, 150; Mag., 100.

Fig. 11. — Carbon vanadium, as forged.

T. S., 118 900 lb.; Elong., 3.5 %; El. L., 103 300 lb.; R. A., 10.0 %; Brinell, 286; Mag., 100.

Fig. 12. — Carbon vanadium, single normalized.

T. S., 119 600 lb.; Elong., 18.0 %; El. L., 80 950 lb.; R. A., 40.3 %; Brinell, 235 ; Mag., 100. Normalized at 1 600° F.

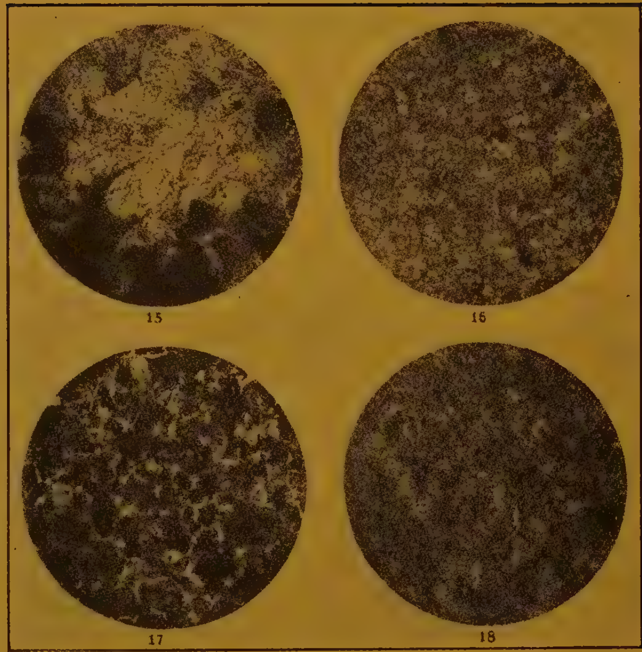


Fig. 15. — Carbon spring steel, as rolled.

Mag. 730.

Fig. 16. — Carbon spring steel, heat treated.

T. S., 213 000 lb.; Elong., 8 %; El. L., 150 000 lb.; R. A., 1 %; Brinell, 384; Mag., 100. Quenched from 1 500° F. in water, drawn at 800° F.

Fig. 17. — Chrome-vanadium spring steel, as rolled.

T. S., 132 000 lb.; Elong., 18.5 %; El. L., 82 300 lb.; R. A., 38.0 %; Brinell, 262, Mag., 100.

Fig. 18. — Chrome-vanadium spring steel, heat treated.

T. S., 215 200 lb., Elong., 11.5 %; El. L., 197 500 lb.; R. A., 32.5 %; Brinell, 430; Mag., 730. Quenched in water from 1 550° F., drawn at 800° F.

after they have been subjected to the various mechanical workings. It will be noted that the structure of the rolled bar, figure 5, contains very large crystals and that they are so interspersed that planes of weakness are set up. This necessarily makes a very poor transverse tensile strength and also leads to brittleness.

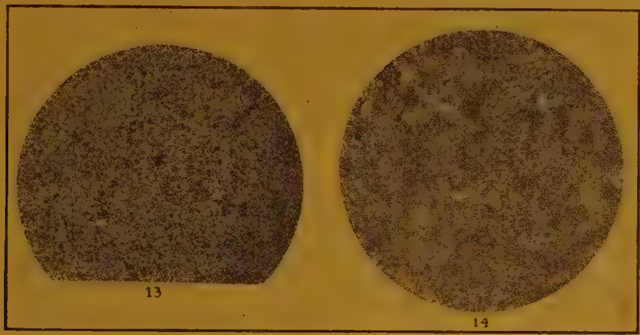


Fig. 13. — Carbon vanadium, double normalized.

T. S., 114 400 lb.; Elong., 22 %; El. L., 77 270 lb.; R. A., 50 %; Brinell, 222; Mag., 100. Normalized at 1 600° F., Drawn at 1 250° F.

Fig. 14. — Carbon spring steel. as rolled.

T. S., 52 200 lb.; Elong,. 43 %; El. L., 86 800 lb.; R. A., 1 %-23 %; Brinell, 289; Mag., 100.

Figure 6 shows the same bar after being subjected to the heat treatment indicated in the caption. The structure is very uniform and dense. The physical properties have been improved. The heat treatment given above is to show the maximum physical properties that can be obtained from common carbon steel for use as superheater bolts and studs. The high elastic limit is obtained in order that the bolts will not stretch during installation.

Character of alloy steels.

Figures 7 and 8 are shown as a comparison of 0.30 % carbon, 1 1/4 % nickel-chrome steel with the 0.40 % carbon steel shown in figures 5 and 6. The only difference in heat treatment of the carbon steel and those shown in figures 7 and 8, is a matter of 25° lower temperature for the nickel steel than for the carbon, and yet the physical properties are very much better in the nickel steel than in the carbon. The elongation is not as great nor is the reduction of area, but the tensile strength is much greater. For this reason this steel is recommended for any purpose where a high tensile steel is required such as superheater bolts or similar purposes. Neither the carbon steel nor the nickel steel should be used in the unheat treated condition. This can readily be seen by the crystalline structures shown in figures 7 and 8.

Figures 9 and 10 show how severe mechanical working under the hammer will change the structure of the material and how a subsequent annealing will make a very uniform material by eliminating the planes of weakness and non-uniformity shown in figure 9. It can be readily

seen how the material is made more uniform throughout its mass by this annealing. It must be understood that these photomicrographs and test specimens are very small portions in comparison with the finished forging, and therefore, it does not necessarily imply that the physical properties shown in figure 9 are prevalent throughout the forging, but they vary greatly in hardness and tensile strength. There is assurance that after annealing the material it will be homogeneous throughout the mass and the physical results obtained after this annealing will be very nearly alike in different portions of the forging. The mechanical strains are also eliminated.

Carbon-vanadium forging steel will give very good results if the proper heat treatment is given the forging. Figure 11 shows that the grain structure is large and that planes of weakness are prevalent. By thorough normalizing, the material is changed to a very homogeneous, compact or dense structure and the forging strains are relieved. Figure 12 shows the structure from a single normalizing. Figure 13 does not show much difference from figure 12 but is should be noticed that the elongation and the reduction of the area are increased appreciably.

Characteristics of spring steel.

If a spring steel is not given a uniform heat treatment, the structure shown in figure 14 will not be obtained throughout the spring bar. It will be more or less made up of crystals of different sizes and hardnesses. This is shown in figure 15 which is magnified 730 diameters to show the hard martensitic structure which would be prevalent in spots in incorrectly heat treated spring steel. Figure 16 shows a uniform martensitic structure throughout the spring leaf. Note the large difference between the ultimate tensile strength and the elastic limit of this carbon spring steel.

Non-uniformity is just as liable to happen in chrome-vanadium spring steel when not made and heat treated properly, as in carbon spring steel. Figure 17 shows crystals of various sizes and hardnesses when the steel is not heat treated. Figure 18 shows a very dense structure and a uniform display of martensite throughout the material, due to proper treatment. There is but a small difference between the elastic limit and the ultimate tensile strength of chrome-vanadium spring steel, which is one of the main assets of this steel for spring purposes. The resistance to fatigue is another feature of chrome-vanadium spring steel.

621 .39 & 656 .25

Electrical power for railway signalling and communications, [1]

By M. G. TWEEDIE,

HONORARY SECRETARY, INSTITUTION OF RAILWAY SIGNAL ENGINEERS, LONDON.

Figs. 1 to 10, pp. 778 to 789.

(*Proceedings of the Institution of Railway Signal Engineers.*)

SYNOPSIS.

INTRODUCTION

Reference to Mr. Bound's Presidential address.

Paper divided into three sections.

Characteristics and application of sources of power only to be dealt with.

Requirements of electricity supply defined and discussed and data given.

SOURCES OF SUPPLY (Section I).

Primary cells. Dry and wet. Various types. Characteristics discussed.

Portable accumulators. Charging and distribution arrangements.

Conversion of power from supply systems.

Independent plant. Steam, petrol-electric, wind wheels, hand generators.

CIRCUITS (Section II).

Various types of circuit.

Circuits grouped.

Circuits operated by minimum power.

Polarized circuits.

Current saving devices.

APPLICATION OF SOURCES OF POWER (Section III).

Points which have to be considered, enumerated, and discussed at length, and various forms of power supply suitable for various requirements and conditions are selected. Reliability— Primary and secondary cells. Public supply. Separate and common batteries. Low annual cost— Centralisation of source of power in one place.

Comparison between primary cells and power plant. Universal battery. Common battery. Centre earthed battery. Application of portable accumulators.

Alternating current supply and methods of application, including conversion.

Common batteries for telegraph offices. Telephone exchange and control office requirements. Suitable types of plant.

Voltage characteristics and internal resistance.

Noise and fumes.

CONCLUSION.

Problems and questions requiring attention.

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(1) Paper read on the 8 December 1926 by the Author, before the Institution of Railway Signal Engineers.

In the presidential address of Mr. A. F. Bound delivered by him on 11 February 1925 before this Institution, there appears the following :

« A direction in which our Institution might do some valuable work would be to investigate and report on the subject of the cheapest and best means of producing electrical energy for all the various functions employed, from an electrical interlocking frame down to a simple high resistance indicator, and included should be a reference to any available means for reducing the current consumption. »

Up to the present it has not been possible to do any work in this direction, and as there is very little information on the application of electricity for railway signalling and communications it is hoped a paper on the subject, from the trunk line point of view will be helpful.

The power question on electrified suburban and tube railways is not being dealt with.

It is proposed to divide the paper into three sections :

1. Sources of electricity usually available;
2. Circuits and apparatus using the power;
3. Applications of various sources of power to circuits and apparatus.

No attempt will be made to describe in detail various apparatus and plant available, but their characteristics and application will be reviewed and discussed.

Where an omission is noticed, a contribution to the discussion which will fill the gap, is cordially invited.

The requirements of an electricity supply or power plant are :

a) Reliability of supply;
b) Cheapness in annual cost;
c) Cheapness in first cost;
d) Easy to understand and maintain;
e) Steadiness of supply.

With regard to reliability, the question of putting « all the eggs in one basket » has to be carefully balanced against the great economy which generally can be obtained by using a common source of power, whether it be a bank of primary cells or the supply from a local authority.

With the great power supply systems now in operation and the gradual linking up of power stations in the future, the complete failure of supply from a local authority becomes more and more remote. Under certain military and labour contingencies a general failure of electric supply is possible, but when these circumstances arise, the importance of signalling will probably be slight.

The reliability of supply is generally of first importance for an interruption will in some cases cause the complete stoppage of trains and in many cases train delays, all of which cost money, besides the dislocation of business outside the railway itself.

There are a number of causes of unreliability and failure of supply when primary and secondary cells are in use.

The exhaustion of the cell is probably the most common. By exhaustion is meant that the closed circuit terminal voltage of the cell or battery of cells is below normal. The reason for this may be that the wattage taken has been in excess of the normal, causing premature exhaustion and in consequence the use of the circuit, the insulation of the circuit and the condition of the apparatus connected therein should be examined. To ascribe a failure to run-down cells, when the circuit is worked abnormally, or is faulty is hardly correct, as it is the result of the overwork or defect.

When stationary or portable secondary cells are used, insufficient or incorrect charging will result in premature discharge, which can also be caused by internal short-circuits.

Failures due to mechanical breakages such as broken wires on zincs, loose or broken terminals, cracked containers,

broken accumulator plates, can be avoided by careful designing and maintenance. The housing of cells has an important bearing on the liability to failures due to mechanical causes. Batteries situated so that coats and tools can be placed on them or rain, sun, or dirt, get at them, or so placed that they can be knocked by passers-by, are sure, sooner or later, to give trouble.

A satisfactory method of easily and accurately ascertaining the state of discharge of all types of cells has not yet been discovered. An American version of the caustic-soda primary cell has the zinc plate so proportioned that it is eaten away when the limit of capacity is reached. The lead-acid accumulators can have the specific gravity of the acid electrolyte measured, but for measuring the state of discharge of Leclanché type cells, dry cells and nickel-iron accumulators the voltage test on closed circuit seems the only one available and it is admittedly not entirely reliable, the accuracy of the instrument and the way it is read being two uncertain factors.

It is quite impossible, on account of expense alone, to provide all circuits with integrating meters to show the power taken to operate them and so measure the output with precision, and in consequence attendance charges must be incurred to enable the necessary testing to be carried out.

Coming now to cheapness in annual cost of a source of power (see also Section I). Cheapness must be viewed from the broadest stand-point. The question can be asked, why cannot electricity at 3 d. per B. T. U. be used for feeding, for instance, the repeater circuits from a distant signal or to operate distant signal machines ? There is certainly no technical reason why it should not be so used, but the first cost of the plant to do it would be excessive, seeing that arm and lamp repeater circuits only require 0.4 B. T. U. per year from the batteries. The connection to the local supply, the transmission line, the apparatus for reducing the voltage to the required amount, various switches, fuses, and metres, etc., which have to be provided before the cheap electricity can reach the apparatus it is to operate, make it at present an uneconomical arrangement. It is possible, however, that simple conversion devices will become available and the repeater apparatus and circuit be altered or re-designed.

At the other extreme there is the large all-electric signalling installation with a constant detection current of some amperes flowing, with frequent rushes for a few seconds of 3 to 5 amperes, or again the common battery telephone exchange requiring 10 amperes or more when it is busy. These are the places where cheap power can be used with advantage. It would not be cheap to use primary cells to supply power for such installations, although they require no cables, metres and other expensive apparatus. The cost per annum for electricity from such a source would be excessive.

The table I gives the approximate cost of obtaining 1 000 watt-hours or 1 Board of Trade Unit from various sources, including wet and dry primary cells and portable accumulators. It will be noticed that to obtain this power, some cells, while their first cost is low have to be replenished frequently, whereas a more expensive cell will, as may be expected, give this output without needing attention.

The discharge of the cells has been taken down to the normal limiting voltage as generally recognised or as given in specifications of purchase.

The figure for the portable lead-acid accumulator includes electricity, labour in charging station and handling and transport to and from the lineman. An allowance for depreciation of the cells is also required when calculating costs.

Where a plentiful and steady supply up to about 7 B. T. U. per week is requir-

TABLE I.

Approximate cost of 1 000 watt-hours (1 Board of Trade Unit) from various sources of electrical energy.

SOURCE.	Average voltage per unit cell, in volts.	Normal constant discharge current, in amperes.	Capacity at normal current, in ampere hours.	Capacity at normal current, in watt-hours.	Frequency of replenishment of source of power to get 1 000 watt-hours.	Approximative cost per 1 000 watt-hours.
Electric supply station . . .	...	...	...	...	...	say 2 d. or 3 d.
1.5 kw. Wind-mill plant with storage battery.	100-120 from battery	1.0	190	19 000	...	11.3 d.
1.5 kw. Petrol-electric set with storage battery.	100-120	1.0	80	8 000	...	18 d. (1)
Lead-acid portable accumulator	2	1.0	120	240	4.16	2 sh. 6 d.
Ditto	4	1.0	40	160	6.25	3 sh. 8 d.
Nickel-iron potash solution accumulator	1.25	1.0	80	100	10	6 sh.
Zinc-carbon cell with air depolarizer and salamoniac excitant	0.95	0.25	500	475	2.1	14 sh. 6 d.
Large dry cell.	1.0	0.1	204	204	4.9	22 sh. 6 d.
Ditto	1.0	0.1	96	96	10.2	29 sh.
Zinc-copper oxide cell caustic soda excitant	0.65	2.0	1 000	650	1.54	30 sh. 6 d.
Ditto	0.65	1.0	500	325	3.06	35 sh. 6 d.
Zinc-carbon cell with manganese depolarizer and salamoniac excitant . . .	1.0	0.1	30	30	33.3	41 sh. 6 d.

(1) Excludes capital charges.

ed the portable accumulator is the least expensive.

Power generated by small isolated power plants is usually the most economical arrangement for loads of more than 7 B. T. U. per week when a supply from a local authority is not available.

Coming now to cheapness in first cost. Owing to their simplicity and the absence of any necessity for special accommodation or apparatus, resulting in low installation charges, the use of dry and wet primary cells has been resorted to in many instances.

When power is required in any amount say, more than 50 watts, it is cheaper to instal a battery of 120 ampere-hour 2 volt portable accumulators.

With larger demands requiring 110 volts, a supply from a local supply company or the provision of some form of small power plant is to be preferred.

First cost is closely bound up with annual cost and considerable judgement and experience are required to select the best combination resulting in low first cost and low annual charges.

Steadiness of supply is important as variations in voltage may have serious effects on signalling and other circuits.

A voltage curve which slopes, having a 33 %-50 % difference between the commencing and final values, makes the source of power from which it emanates unsuitable for some purposes owing to the necessity for either constant adjustment of the circuit values or over-volting the circuit to start with, with undervolting towards the end of the cells life.

The lead-acid accumulator and soda primary cells have a usefully flat voltage curve, the variation over the final voltage being in the neighbourhood of 2.1-1.85 = 13.5 % for the lead-acid accumulator and 16.5 % for the primary cell.

The voltage of supply services from local authorities being usually steady makes such a source of power very suitable if it can be applied direct. This can be done when alternating current is available, circuits being fed through transformers and if desired, small static rectifiers.

As regards ease of maintenance, while evening classes and correspondence courses enable some technical knowledge to be acquired, it remains still difficult to find men willing and able to look after complicated plant. The extra skill required justifies higher remuneration which factor has to be borne in mind when designing installations. Every endeavour should be made to keep plant simple without sacrificing reliability and efficiency. Plant requiring the services of the manufacturer's staff should certain parts of it go wrong or get out of adjustment, is not suitable for railway signalling purposes.

SECTION I.

Sources of supply.

The earliest form of generator of electricity for railway signalling and communications was the primary cell, many different forms being employed. These have now settled down to the zinc-carbon combination with a salamoniac excitant and a depolarizer, either in the dry or wet form of cell, and the zinc-copper oxide combination in caustic-soda solution in a wet cell form.

Much attention has been and is being paid to the design of primary cells with the result that a number of excellent types are available.

The draw-back of the soda cell is its low voltage 0.65 which necessitates a larger number of cells for a given voltage than when the salamoniac cell is used. Besides increased first cost, more labour in attendance and greater accommodation space are required.

The primary cell still appears to be a difficult problem for the best dry cell gives approximately 200 watt-hours at a cost of about 22 sh. 6 d. per 1 000 watt-hours, after which what is apparently a new cell from the outside appearance has to be thrown away.

When these cells are broken up, the large amount of zinc left raises questions regarding the proportioning of the constitutents of the cells. Cannot such cells be designed so that all the elements are consumed together and so save waste of some of them due to the exhaustion of the other part of the cell ?

With regard to the wet cell, this lends itself to replenishment, but necessitates the provision of a sink and a water supply in battery rooms and linemen's huts.

The nature of the excitant used may cause difficulty. A corrosive solution is unpleasant and not easy to handle and increases the cost of the energy obtained in consequence.

The cost of electricity obtained from these cells is very considerable and every endeavour is made to get the utmost out of the elements employed.

The difficulty and labour involved in replenishing wet primary cells approaching exhaustion, situated some distance from sinks and water, add greatly to the cost of the electricity produced and recourse has had to be made to some other means of obtaining the electrical energy required. During the last twelve years the use of the portable lead-acid accumulator has been greatly extended. The accumulator of this type has an almost flat voltage curve and negligible internal resistance besides the highest voltage of any cell.

Recharging is easy and cheap but to obtain the full effect of these advantages a well organised system of distribution is required, and such a system is now described.

Every circuit using an accumulator or battery of accumulators must have its own code letter and number, and lists of these circuits must be prepared and kept corrected. A rigid time-table must be prepared for the use of the lineman showing him when each accumulator has to be replaced by a charged cell and removed from its circuit and returned to the charging station. Likewise another time-table is required for the accumulator charger showing the date, train, and destination of accumulators to be sent away.

To every circuit is allotted a lead or fibre disc or tab bearing a code letter and number. One disc is placed in the accumulator cupboard or box and the other is placed in a special rack in the accumulator charging room.

Every cell which is sent out in addition to its individual number has attached to a terminal a disc (which has a slot cut in it) bearing the code of the circuit for which it is intended.

The lineman on receiving the accumulator substitutes it for the partially discharged accumulator, removing the slotted disc from under the terminal nut. The disc is then attached in a like manner to the terminal of the discharged cell and it is returned to the charging station.

The dispatch and receipt of cells are recorded on special forms and the non-return of any cell can be detected with ease.

For travelling purposes, portable accumulators are carried in detachable carriers and enclosed in strong wooden boxes, which usually hold four cells.

To ensure interchangeability, the dimensions, voltages and capacities of cells must be kept similar. In practice it will be found that 2-volt 120 ampere-hour and 4-volt 40 ampere-hour accumulators will be sufficient to provide all the various combinations required.

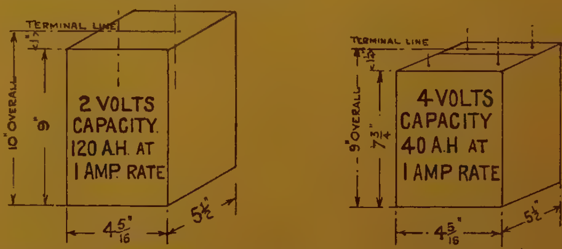

Fig. 1. — **Portable accumulators, 2-volt and 4-volt types. Not to scale.**

Figure 1 illustrates the two types of portable accumulator suitable for signalling work.

These cells have stout celluloid containers, so that the acid level and condition of the cell generally can be easily seen.

The plates, separators, bottom rests, vents and terminals should be such that violent treatment will not cause premature discharge. As the recharging is done by the constant current method they should be designed accordingly. Weight must be kept down to a minimum. A life of more than three years should be obtainable.

When power is required from supply systems in some quantity, the transformation to the required pressure is most economically carried out by motor generators, alternating current or direct current, being converted to say 24-36 volt direct current with ease. Small 0.5 kw. direct current motor generators have an overall efficiency of about 42 % and alternating current motor generators of the same size about 47.5 %.

Such plant is best suited for charging accumulators where continuous running of the set from one week's end to another is not necessary. A duplicate battery is usually provided with such plant, one battery being on discharge while the other is being recharged or standing spare.

An interesting type of motor generator accumulator charging plant has recently been evolved in which the battery is divided into sections and each section is charged separately, but is not disconnected from the load. The duplicate battery is dispensed with and a uniform non-drooping voltage is obtained. As the motor-generator with this plant may only require to charge two cells in series at once, at say 25 amperes, it is a very small and consequently an inexpensive piece of plant, taking very little current from the supply system. It runs, however, practically continuously, a train of gears being driven by it, adjusted to operate a battery switch which changes over the charging of a section of cells to the next section, as desired. A voltage control is also available and soaking charges can be given. Figure 2 shows this plant diagrammatically.

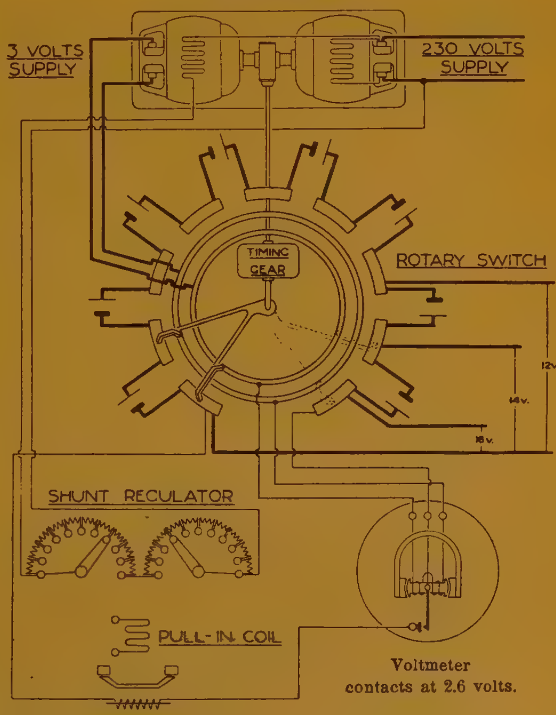

Fig. 2. — Round-about type auto battery charging equipment.

A plant of this type is in use in Scotland feeding groups of track circuits and illuminated diagrams requiring a uniform voltage.

When no local supply is available and yet a considerable amount of power is required, resort must be made to independent power plants, with prime movers deriving their energy from coal, petrol, oil, or wind.

It is possible where a steam plant has

had to be provided for locomotive pumping purposes, such as water troughs or locomotive running sheds, for a small 1 or 2 kw. steam driven set to be installed, charging stationary accumulators twice a week.

Petrol-electric sets are now popular for this class of work and are quite economical both in first cost and running charges. A first-class representative make having a 3-braking horse power single cylinder water cooled engine with a dynamo to give 1.5 kw. direct current at 50 or 100 volts, and an accumulator battery of 80 ampere-hours, would cost approximately £200 with a building.

The cost per B. T. U. generated assuming 7 B. T. U.'s used per week would be approximately 1 sh. 6 d., this to include fuel, oil, maintenance of engine and battery, renewals and attendance.

An oil engine of the self ignition type direct coupled to a dynamo with 260 ampere-hour battery at 120 volts will generate power at 1 sh. 8 d. per B. T. U. if 2 500 B. T. U.'s per year are generated.

There are places so exposed that wind can be made use of, and in this connection the report on the « Use of windmills for the generation of electricity » issued by the Institute of Agricultural Engineering, University of Oxford, is worthy of careful perusal.

Therein is described nine types of plant. In some, the dynamo is gear or chain driven by the wind wheel, and in others the dynamo is on the same shaft and housed against the wind wheel. In tests made in 1924-1925 at Harpenden, Hertfordshire, England, a windmill driving a 1.5 kw. 100-120 volt set generated 1 370 B. T. U. during the year. This, allowing for battery efficiency, gives about 20 B. T. U. available for use per week; more than enough for many signalling installations.

Such a plant costs approximately £350, and the cost per B. T. U. available for use 11 sh. 3 d., which includes depreciation of plant and battery plates, etc.

It is interesting to note in view of present labour costs, that the maintenance and repairs are estimated to come to about £3 10 sh. per year.

The data regarding wind shows that during the 8 760 hours in a year, there was wind for 89.9 % of the time, there being calm for 10.1 % of the year. During May and September, no calm periods occurred; June, July and August had 687 hours calm, or 31.1 % of the total hours of these months. During these months 92.13 B. T. U.'s were generated, and allowing for battery efficiency, this gives 69 B. T. U's available for use, or 750 watt-hours per day. A 100-volt 120 ampere-hour battery is considered sufficient for a plant of this size to carry over the longest calm period. It is important to choose a plant carefully in relation to the anticipated load during the summer.

A source of power adopted when primary and secondary cells, are objected to, is the small hand-driven generator, giving either alternating current or direct current.

For circuits requiring low frequency alternating current *viz.*, 12-18 cycles, such as magneto telephone bells or indicators, etc., a hand turned magneto is popular for small telephone installations.

For the operation of electrically operated point motors, signals, etc., a small direct current dynamo, the armature of which is revolved by a handle through gearing, is finding application in a number of installations. These dynamos give out about 120 watts at 100 volts and points are moved over by a few turns of the handle. When used on a circuit where a « hold-off » current is required, a primary battery is brought into use by a relay when the dynamo ceases to generate.

SECTION II.

Circuits for signalling and communications.

The circuits employed for signalling and communication purposes are extre-

mely varied. There are circuits requiring a few milliamperes at 1-3 volt direct current, once or twice a day, and at the opposite extreme are steady demands of many amperes alternating current at a pressure of 110 volts or higher.

Between these extremes will be circuits requiring a direct current supply of a few milliamperes at 100 volts or more, the current being taken in short rushes, offers an absolutely steady supply voltage although the current demand may vary considerably. There will also be circuits requiring the voltage curve to be perfectly smooth and the source of power, if a battery, to have negligible internal resistance. Quite a number of circuits require the reversal of the polarity of the operating current.

There are also circuits the interruption of which may result in trains being checked or completely stopped, or communications may be broken down or again the failure of a circuit to function may merely result in nothing more serious than inconvenience.

The result of these varied requirements is that the source of power suitable for a particular circuit should be chosen only after careful examination of the circuit's characteristics, and this part of the subject is dealt with in Section III of this paper.

Circuits may be divided into two main groups : *a*) intermittent; *b*) continuous (steady or fluctuating) current. Intermittent may be defined as a circuit taking current for less than one minute.

In this class *a*) are grouped the following : office bells, selective currents in telephone circuits, ringing current in telephone circuits, block bell line current, block bell local current, signal machines (high and low voltage), point machines (high and low voltage), single needle instruments, certain telegraph circuits, electric locks, transient track circuits, certain telephone signalling lamps, telephone exchange eye-ball indicators, and drop indicators.

In the continuous current class *b*) can be included track circuits, either feed by direct current and alternating current, local winding of two-element alternating current relays, electric detection circuits, electric lamps in illuminated diagrams, electric signal lamps, both day-colour light or instead of oil burners, lamps in lever lights, common battery telephone exchanges, common battery control tables, ringing vibrators, bloc disc instruments, arm repeater « on » circuit, arm repeater « off » circuit, light repeater « in » circuit, track indicators, repeat relays, fire alarm systems employing constant currents.

Table II gives some data for a few representative pieces of apparatus. For estimating the ampere hours required by various circuits, when the current is steady and continuous, the curves given in figure 3 are useful. One set of curves is for current passing with different resistance values when connected to 2-volt or 4-volt accumulators. Another set of curves gives the ampere hours taken at a given current value over periods of one week, a fortnight, one month, etc.

In the past it has been the object of instrument and apparatus designers to reduce the watts necessary for operating signalling apparatus to the minimum, with a view to economising battery power.

The exquisite workmanship and ingenuity in design resulted in a microscopic power consumption and instruments became so sensitive that a limit in minimum operating current has had to be introduced into specifications, to prevent such apparatus responding to earth currents due to magnetic storms, leakages from power systems, electric railways, etc.

Careful circuit design has obtained economy in power, by the use of various forms of relays to switch on power locally and thus save transmission losses. Such arrangements are found in some power signalling systems where the pow-

TABLE II.

Current and watts taken by various apparatus.

INSTRUMENT OR APPARATUS.	Resistance. Ohms.	Normal working current. Amperes.	Watts taken. C^2R. by apparatus.	Nature of demand.
Signalling apparatus.				
Track indicator	1 000	0.005	0.025	Continuous.
Detection relay	1 000	0.012	0.144	—
Track indicator	400	0.010	0.040	—
— —	250	0.016	0.065	—
— (type) relay	250	0.012	0.036	—
Block disc (Spag : movement)	170	0.010	0.017	—
Repeater (arm)	170	0.007	0 008	—
Repeater (light) Spag : movement	50 and 150	0.012	0.036	—
Block bell line relay	50	0.100	0.500	Intermittent.
Track (type) relay	50	0.030	0.045	Continuous.
Electric lock (Great Western Railway)	20	0.400	3.200	Intermittent.
Block bell local circuit	10	0.500	2.500	—
Track relay	9	0.055	0.027	Continuous.
— —	4	0.077	0.023	—
Track circuit feed 2 volts	...	0.200	0.400	—
Lamp, M. F. 12 volts	...	0.250	3.000	—
Telegraph and telephone apparatus.				
Single needle	130	0.010	0.013	Intermittent.
Double current circuit polarized relay	200	0.0005	0.00005	—
Polarized sounder	1 000	0.010	0.100	—
Sounder local	20	0.055	0.006	—
Switchboard eye-ball indicator	500	0.048	1.152	Continuous.
— lamps, 24 volts	240	0 100	2.400	—

er to the point, or signal motors, signal lamps, etc., is switched on direct by a circuit controller, or again, the power for an electric lock is controlled by a repeat relay in a local battery circuit.

Motor driven horns are also controlled by relays in the same way.

The use of the catch-rod contact, hand plunger or foot-plunger in an electric lock circuit is a current saving device.

The transient track circuit system is an attempt to save the constant drain of power through the ballast and relay when no vehicle is near or on the track circuit. The saving would about 9.4 watt-hours per day.

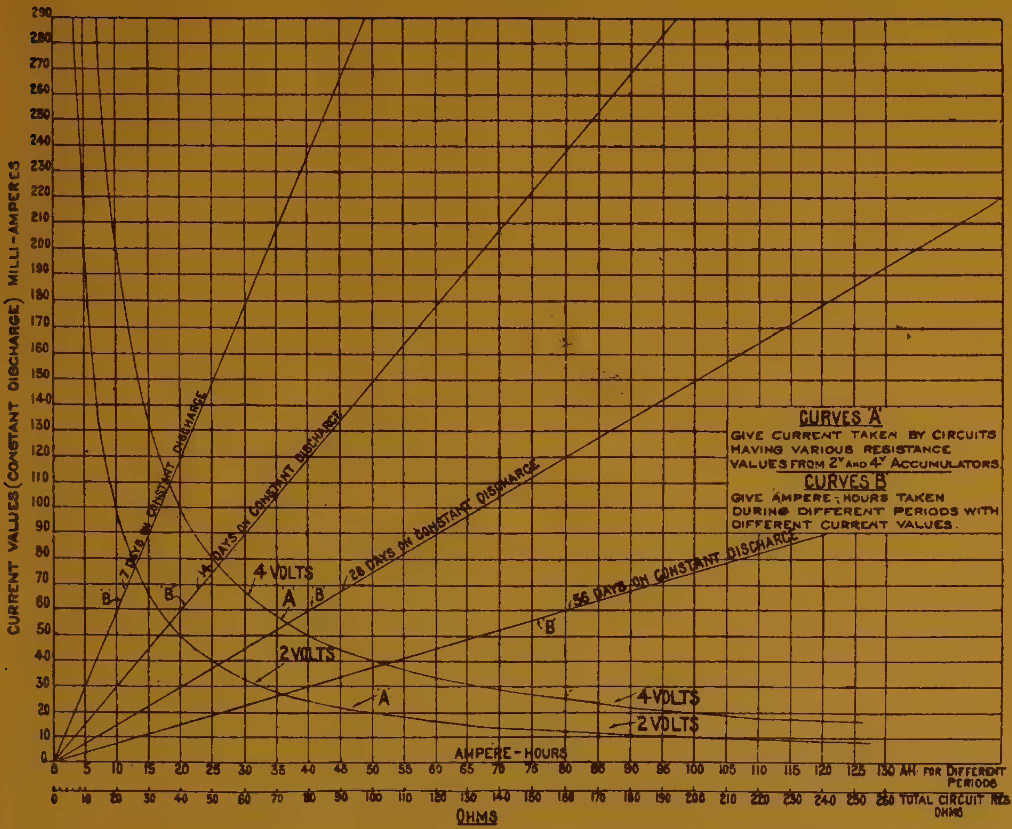

Fig. 3.

The preference for a continuous indication of the state of an unoccupied track costs something for the provision of power, whereby such an indication is given. The most economical indicator takes about 220 watt-hours per year. The three-position block instrument which is also used to indicate the presence of trains on the track is allowed to show « line closed » and takes no energy when the line is unoccupied.

The signalling principle requiring the « stop » or « danger » indication or effect to be given should power fail, by its very nature demands a steady drain of energy and no reduction can be made which runs contrary to this principle.

SECTION III.

The application of the source of power.

The various sources of electricity and the circuits requiring it having been reviewed, the stage is now reached when the selection of the most suitable source of power for any particular purpose can be discussed.

When dealing with this question, the following points need consideration :

1. Is it vitally important that there shall be no interruption of supply ?

2. Is low annual cost of the utmost importance ?

3. Is skilled attendance available ?

4. Must the voltage curve be flat for all loads and not droop at all towards the end of some days ?

5. Must commutator ripple or similar irregularities be entirely absent from the voltage curve and must the internal resistance of a proposed battery be negligible ?

6. Must the plant installed be silent and odourless in operation ?

7. Is the operating current to be reversible in polarity ?

For circuits the interruption of which results in serious consequences it is generally recognised that a first class primary or secondary cell or cells are the best means of supplying power, depending on the nature of the circuit to be operated. A well maintained accumulator battery is very reliable and suitable for many important purposes. The recharging of such batteries requires plant the reliability of which while important is not vital, owing to the usual storage margin allowed when selecting accumulators.

The choice of separate battery and central or common battery systems depends on the opinion as to which is the more reliable, viewed from the widest point of view.

The supply given by local authorities from their power stations is in most cases of a high standard of reliability and can be depended on for most purposes.

When low annual cost is of the utmost importance the correct arrangement of the primary cells when used or the centralization of the battery and power plant ensures that the energy is used in the most efficient manner. If primary cells are used, it is important when connecting them up to bear in mind one of the rules laid down by the late Dr. S. P. Thompson, regarding the grouping of cells. For grouping of cells to ensure the best economy, he says : « So group the cells that their united internal resistance shall be very small compared with the external resistance. In this case the materials of the battery will be consumed slowly, and the current will not be drawn off at its greatest possible strength; but there will be a minimum waste of energy. »

For the constant or fluctuating current circuit of 24 volts or over, taking more than 0.25 ampere or 42 ampere-hours per week, a small plant taking power from a public supply at 3 d. or less per B. T. U. may be considered.

When a public supply is not available, a battery of 120 ampere-hour portable accumulators is economical.

If 96 ampere-hour dry cells are used, the cost of such cells per annum would amount to approximately £80, whereas a small accumulator plant of 50 ampere-hour cells would supply the circuits requirements for £10 including depreciation and renewals. Figure 4 gives some curves whereby the annual cost of power at various prices per kilowatt-hour can be ascertained when the daily consumption in watt-hours has been determined.

To save cells, the Universal battery system (fig. 5) has been in use for many years, groups of similar pieces of apparatus, such as single needle telegraph instruments being connected to one battery, the requisite voltage being obtained by tapping the battery at various voltage points.

A development of this idea is the common battery system (fig. 6) which can be adopted with advantage where there is a group of various and different types of instruments, such as a large signal box or telegraph office. Such a battery, if it is considered as a single battery, must have its centre earthed, which also applies to the Universal battery.

From the positive, negative and earth terminals of the common battery are run leads to 'bus bars in a resistance cabinet near the apparatus. Each circuit is fed from the 'bus bars through suitable re-

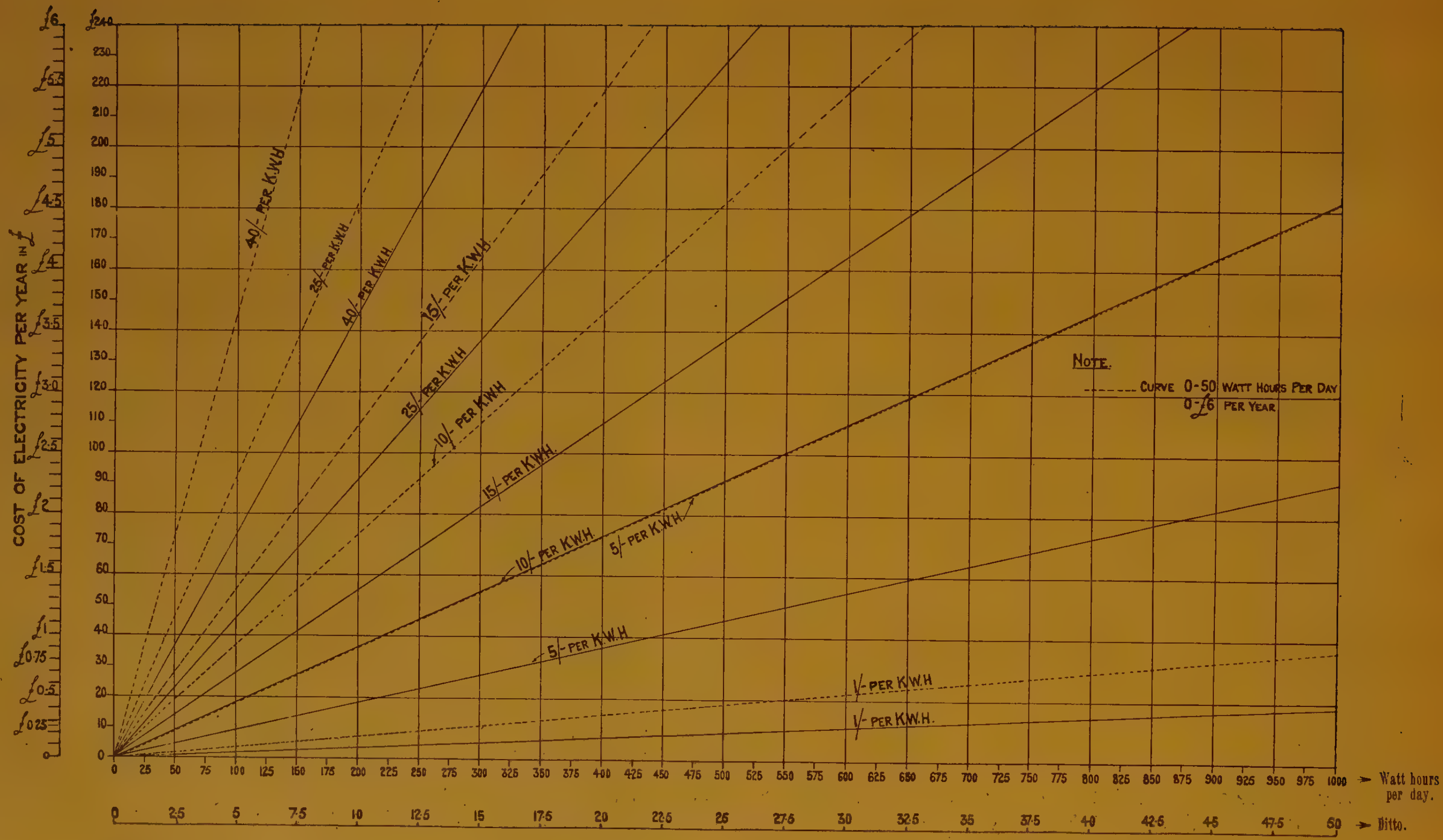
COST OF ELECTRICITY PER YEAR IN £
Watt hours per day.
Ditto.
NOTE.
CURVE 0-50 WATT HOURS PER DAY
0-£6 PER YEAR
40/- PER K.W.H
25/- PER K.W.H
40/- PER K.W.H.
15/- PER K.W.H
25/- PER K.W.H
10/- PER K.W.H
15/- PER K.W.H.
10/- PER K.W.H.
5/- PER K.W.H.
5/- PER K.W.H
1/- PER K.W.H
1/- PER K.W.H.

Fig. 4.

sistances connected thereto. By this method a 48-volt centre earthed battery of 120 ampere-hour portable accumulators in a signal box will supply the key discs, block bell, line and local circuits, lock indicators and track circuit indicator circuits for two months if required, as such a signal box takes approximately 1.2 ampere-hours per day.

For smaller signal boxes the same method can be used with primary cells. By the adoption of the common battery system many cells are dispensed with, which are now necessary with the separate battery system. The reduction of the number of cells required from, say, 150 to 50, enables the specially built battery room to be dispensed with and this sometimes saves between £50 and £100 in the construction of a signal box. A battery cupboard under the signal box affords ample accommodation for the small number of cells required.

The use of dry primary cells to feed track circuits while being simple is the most expensive method, particularly when a 0.5 ohm or higher train shunt is required.

Track circuits in inaccessible positions such as those in use with controlled advance section signals or semi-automatic signals, can be fed by portable accumulators, distributed weekly or fortnightly by special train. If such an installation is in the neighbourhood of a first-class alternating current electric supply, the following methods can be adopted :

a) Take the alternating current direct at 110 volts to suitable rectifiers connected to the rails. This has the advantage of simplicity and the direct current relays and other apparatus can be retained. It is also most economical in power and hardly any attendance is required. A track circuit fed by this method takes from the supply system approximately 9 B. T. U. per annum;

b) The rails can be fed by alternating current stepped down, alternating current relays and other apparatus being employed. This is expensive both in first cost and power consumption, but possesses the merit of being immune from stray direct currents such as may be experienced with electric traction, or in the neighbourhood of electric trams;

c) The alternating current to be taken to rectifiers, the floating battery system being adopted (fig. 7).

At appropriate points the power line is tapped by a transformer which reduces the transmission pressure to say 110 volts. The alternating current is then converted to direct current, an accumulator battery of small capacity, say, 10 ampere-hours or so, being connected across the rectifier or motor-generator terminals. The load is connected across the accumulator terminals. By careful adjustment the voltage can be maintained constant and the accumulators will be kept in a fully charged condition. If track circuits are connected to such a battery, the rectifiers or motor-generator will in effect supply the feed watts. When signal machines are connected to a floating battery, the rush of five amperes or so when a signal is worked off is drawn from the battery and the trickle charge replaces the loss afterwards. The small and uniform nature of the demand on the supply line enables a minimum size of conductor to be used, resulting in low installation costs;

d) Another system used when alternating current is available, is to have two sets of accumulators, one being connected to the lead and the other being recharged or standing spare. As the cells with this system are of larger capacity than with the floating battery system, a larger storage margin is available, should the main supply be interrupted. The system however needs larger rectifiers or motor-generators and the demand on the transmission line necessitates a larger conductor. It is also necessary for the accumulators to be changed over by hand or other means at stated intervals.

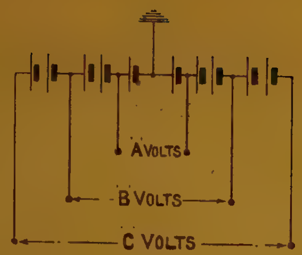

Fig. 5.
Universal battery system.

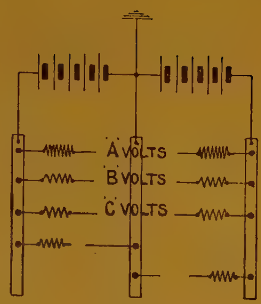

Fig. 6.
Common battery system.

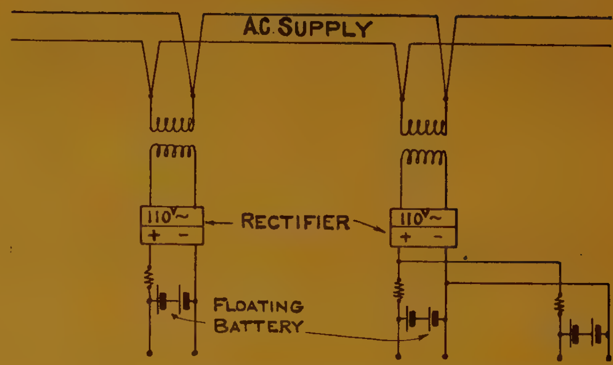

Fig. 7. — Alternating current trickle charge system.

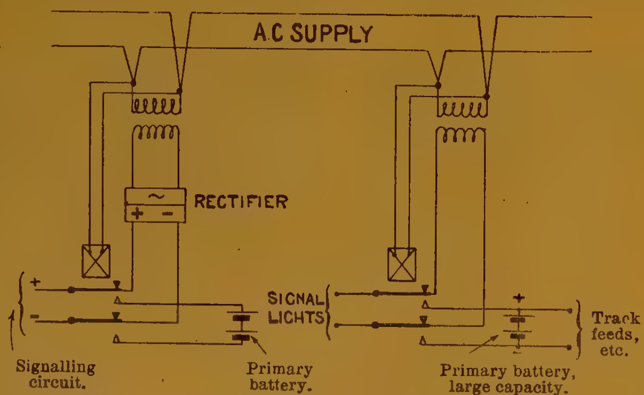

Fig. 8. — Alternating current primary battery systems.

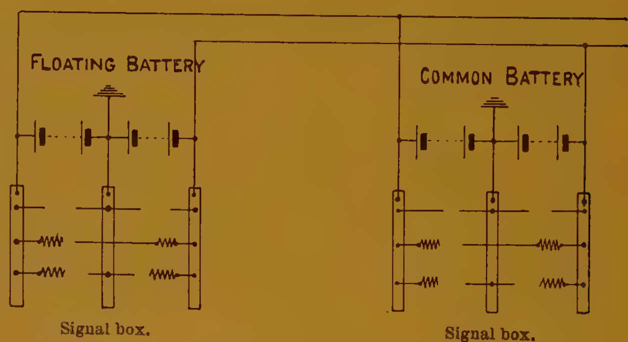

Fig. 9. — Common and floating battery system.

A number of types of alternating current to direct current rectifiers are available, some designs using a vibrating or moving member which moves in phase with the alternating current, others employ thermionic valves, others electrolytic valves, and some of the largest use a bulb filled with mercury vapour in which an arc glows. A small rectifier is also available, consisting of discs of certain metals, no moving parts, gases, or liquids being required. The overall efficiency of rectifiers varies between 40 % and 80 %.

Alternating current transformed to the required voltage or rectified and used direct for operating circuits [see *a*) and *b*)] while economical in *a*) and immune in *b*) is liable to complete failure. This has been met by a system having reserve batteries of primary or secondary cells, with automatic switching, which will bring them into use should the alternating current fail. Signal lamps can be kept alight by this method, but the alternating current signal and point machines and alternating current relays, etc., would remain out of action until the alternating current was restored. Figure 8 illustrates two methods of applying this system.

When an electric supply is available at a station or junction with a number of signal boxes, and perhaps a telegraph office, central batteries of accumulators of 28 volt and 120 ampere-hour capacity can be provided charged from the supply by a suitable machine.

At the signal boxes should be installed 24-volt batteries of accumulators of 10 ampere-hour capacity two batteries being joined in series with centre point earthed. The circuits to be fed should be connected through a resistance cabinet as already described. Each signal box battery, other than the central battery, is fed by two wires and a trickle charge of 50 milliamperes or so. Figure 9 shows this system, with the main battery in one of the signal boxes.

This system saves many primary cells and battery room accommodation.

For supplying the power required by a telegraph office, other than one which can be fed as above, primary cells while cheap to instal and simple to look after, are most expensive to maintain if the office is of any size. The usual method of using cells, is to put the fresh cell on the more heavily worked circuits and after its voltage has fallen somewhat, to change it to more lightly worked circuits and so on until it is discharged. This all means attendance and constant testing.

If an alternating current supply is available, batteries of small accumulators can be installed, charged in sections by a rectifier of some kind, the instruments being fed through resistances from common 'bus bars. Such a system was introduced into one telegraph office and effected a saving in annual maintenance of more than £200 per annum at a cost of £25 per year.

For charging large numbers of portable accumulators at once, a direct current supply is essential for cheap installation cost, as the charging can be done direct from the mains. If alternating current only is available, a large mercury vapour rectifier or a motor generator is essential. As not more than two types of cell should be in use, the charging room, which should preferably be divided into brick cubicles, can have the shelves long enough in each cubicle to take 90 2-volt and 45 4-volt accumulators in series, when the supply is 230 volts direct current; cubicles being allotted to each type of cell. Adjustable resistances or special banks of carbon filament lamps in series with the cells enable current regulation to be effected. Different sizes of cells must be kept together. Figure 10 shows accumulators charged from a direct current three-wire system.

With such a plant charging 2 000 cells per month, an average of 0.4 B. T. U. per cell of both types will be used, the total

cost being about 6 d. per cell distributed to the linemen.

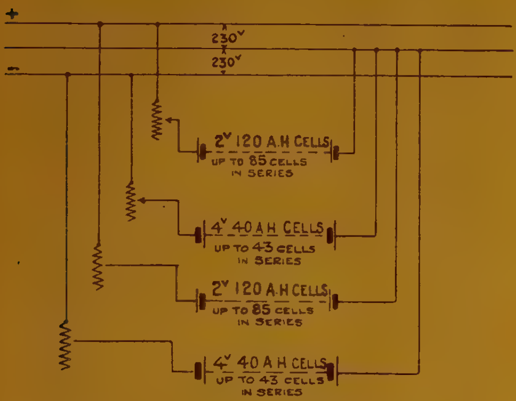

Fig. 10. — Portable accumulator charging.

It is most essential that the cells should be entirely insulated from the shelf and from each other; 2-inch glass strips, 1/4-inch thick, held on edge in lead feet, two strips side by side make excellent insulated and acid-proof stands.

For feeding common battery telephone exchanges, a 24-volt accumulator battery is almost universally used, except in small exchanges, when large primary cells may be adopted. The accumulator battery is usually provided in duplicate, one battery working the exchange while the other is on charge. The positive terminal of the working battery is earthed. It has been found that to charge a battery while it is connected to a common battery exchange results in the commutator hum being audible in the receivers, unless special impedances are introduced to smooth out the ripple. These impedances connected in the output lead from the battery are considerably used to save a second battery. A practical difficulty however arises when the single battery requires taking out of use for replating, etc.

The automatic plant referred to in the first part of this paper which charges sections of its battery in rotation is also suitable for exchange work, and is free from ripple and the accumulators can be readily renewed, section by section.

For working vibrators or ringers for exchanges, it is necessary to feed them from separate batteries, owing to the ripple trouble. Ringers driven by small direct current or alternating current motors run off supply mains is the most economical arrangement when they run continuously.

Power signalling installations, if direct current, require motor generators and duplicate accumulator batteries of considerable capacity. The usual voltages of 110-120, with 24 volts for indication purposes, and the desire for reliability make the provision of such plant necessary.

Power signalling installations are in use, however, taking alternating current direct from local supply systems which after being reduced to 110 volts alternating current by static transformers, feeds alternating current signals, point machines, relays, and lights without the provision of any running plant. Alternating detection current from 110/20 transformers is used and alternating current circuit controllers placed close to the point machines, operated from the signal box, switch the power direct on to the point motor, resulting in saving in copper in the mains between the signal box and point motors.

For generating power at installations away from a public supply, the use of the modern petrol-electric set will be found satisfactory and economical. At exposed situations it is an open question whether windmill plants would not be the cheapest to run. They have strong claims for consideration. During unusually long periods of calm, a portable petrol-electric set could be brought from headquarters without much trouble to recharge the battery, such a set being able to look after a large number of wind plants. The portable generating set system could be used in other ways, the pro-

vision of separate engines and dynamos being dispensed with when two or more power plants are situated conveniently for rail transport of the portable set.

For working single line instruments, the primary cell is the most suitable for providing the intermittent current at about 30 volts which is usually required. Hand generators are also used for this purpose. Primary cells are best for local battery speaking telephones, battery ringing telephones, office bells and loud sounding bells unless they are motor driven, when portable 4-volt accumulators would give best results. Klaxon horns used for warning purposes or for calling drivers back by code calls, are best worked by 4-volt portable accumulators.

The direct current hand generator is used for operating point and signal motors and all the safeguards associated with power signalling can be furnished. Normal and reverse check-lock circuits for points are arranged and the normal check-lock on signals. For constant currents in the detection circuits, a battery of primary cells is used, coming into circuit after the generator has ceased to work. Such a method of generating electrical energy is suitable for small power signalling installations, where there are a few levers worked occasionally. A power plant is entirely dispensed with in such circumstances.

The question of skilled attendance being available, generally means that where it can be obtained the best and most economical plant can be installed. Such attendance ensures the results obtained outweighing the extra remuneration which will legitimately be expected.

In situations where only semi or unskilled labour is possible, recourse to the simplest form of power is inevitable, the dry cell, the simplest form of wet cell or hand driven magneto or dynamo being adopted. The wet cells would probably have to be made up in some central depot, being handed ready for use to the unskilled labour. The hand driven magneto or dynamo is suitable under these circumstances for circuits requiring an intermittent current for a few seconds, such as ringing a bell or dropping an indicator at some distant point.

The voltage characteristics of a source of power have a bearing on its suitability for some circuits.

The primary cell of the zinc-carbon type has, as already mentioned, a sloping voltage curve 1.5-0.9, but it can be used on intermittent and semi-intermittent work such as office bell, block bell and block disc, and repeater circuits, water level indicators, etc.

The larger sizes of cell are used to some extent for feeding track circuits, but in this size which is somewhat expensive, the only justification for their use is the impossibility of using anything else.

The caustic-soda primary cell has a flattish voltage curve and is for that reason favoured for track circuit feed work but its voltage 0.65 being so low, a high train shunt is not always possible of attainment.

The lead-acid and alkali accumulators, the former giving an almost flat curve at 2.0 volts and the latter at 1.25 volts, are best for feeding groups of track circuits and indicator lamps where a steady voltage is desirable.

Telephone exchanges with lamp signalling must be fed from a uniform voltage supply and the accumulators for large and the caustic-soda primary cell for small telephone exchanges are a good arrangement. For common battery telephone exchange work with common battery speaking, the source of power must be free from ripple or other voltage irregularity which might be caused by internal resistance of the battery supplying the power, the resistance of the leads between battery and exchange or a vibrator or similar piece of apparatus connected to the exchange battery (see also page 789). The lead-acid accumulator

meets these requirements and for that reason is commonly used.

Internal resistance has an important effect on the available voltage, not only reducing it, but causing it to droop. It is interesting to note that to obtain 120 volts from a battery of Leclanché cells, sufficient cells have to be included in the battery to make up for the loss of about 18 volts due to internal resistance. In this case 13 % of the energy generated is wasted in the cells.

There are at times battery or power rooms so placed that the hum of running machines or the smell of the gas given off by accumulators is objected to by the occupants of neighbouring rooms. It may be necessary, if it is a big plant, to move the motor generator, engine set, or large rectifier to a more remote place, but the battery will have to remain near the exchange to keep the copper drop between it and the exchange as low as possible.

Quiet rectifiers are the thermionic and electrolytic types and they can be used without fear of complaint. They are however, small in capacity. The acid fumes trouble is got over by covering the top of the electrolyte with anti-spray oil to the depth of 1/8 inch. Sealed top accumulators also reduce the acid fumes. The prevention of acid fumes enables the accumulators to be erected in the same room as the charging apparatus, switchboard, etc., thereby reducing the cost of accommodation. Another advantage of anti-spray oil is the prevention of evaporation of the water, an important saving being effected thereby.

The two usual methods adopted when the polarity of a direct current source of power has to be reversed, is either by the provision of two batteries one for each polarity or by a reversing switch, key or contact box. When two batteries are used, one pole is usually earthed and in consequence they are not always suitable for all circuits to be worked. It is also found that one battery may be discharged much more than the other and they should be proportioned accordingly. A good, though small, example of this is the signal arm repeater, which requires a battery of twice the capacity for the « on » indicator to that for the « off » indicator.

Conclusion.

Having now reviewed some past and present practices and tendencies relating to the supply of electrical energy for operating signalling and communication apparatus, it is of interest, and perhaps value, to enumerate some of the problems and questions which require an answer. Taking them at random, they are :

1. Is the supply from large power stations sufficiently reliable for signalling purposes, when used direct from the mains ?
2. Cannot standard signalling voltages be adopted ?
3. Will electrical signalling apparatus of all kinds be designed to operate on, say 24 or 110 volts direct current ?
4. Will not the day come when the great trunk railways will have power supply mains for signalling purposes running by the side of their main lines from one end to the other of their systems ?
5. Can a static direct current to direct current converter of good efficiency be produced ?
6. With the data now available, are wind driven plant suitable for producing electrical power for signalling purposes, under certain circumstances ?
7. Cannot some signalling circuits be standardised and so enable, amongst other advantages, the source of power to be standardised ?
8. Cannot sizes, outputs, designs, specifications, etc., of primary and portable secondary cells be standardised ?
9. Are primary cells better than portable accumulators for general signalling purposes ?
10. Is it possible to design primary

cells so that the amount of energy left in them can be accurately and cheaply ascertained ?

11. Is it possible to design dry cells which will keep and stand in use indefinitely without any deterioration ?

12. Can a portable accumulator be designed with a transparent non-inflammable case, which can be dropped, inverted without spilling, which can be discharged and then stand idle and completely recover when recharged, hold its charge indefinitely, give out the maximum discharge required or discharge at a very low rate, have a life of five years, weigh less than 25-lb., not exceed the dimensions given in figure 1 and not cost any more than the present accumulators?

13. Is it really necessary nowadays to spend so much on apparatus in order to save operating watts ?

14. Will the common battery system in signal boxes take the place of the separate battery system, thereby saving cells?

15. Is there anything to be learned from the experience with primary and secondary cells, etc., in large power supply installations, electric train lighting equipments, automobile lighting and starting practice and wireless telephony receiving stations ?

Many important economies in railway signalling and communication plant both in first cost and annual maintenance, have been and can be obtained by a careful examination of electrical supply questions, and it is a field which, as suggested in the Presidential address of 1925, is worthy of much attention.

DISCUSSION.

The PRESIDENT said he was sure all would agree that it had been a most interesting paper, and he suggested that it had come at a most opportune time. Railway signal and telegraph Engineers were now being faced with problems which five years ago they would have deemed impossible to have tackled. He was not going to take up time then to enlarge on that point, other than to say that they had much to thank the manufacturers for, and whilst the manufacture of apparatus had been exquisite, the manufacture of primary and secondary batteries had been equally good. As there are many points of interest to manufacturers in the paper, he hoped to give them an equal share in the discussion.

Mr. W. J. THORROWGOOD thought the paper very interesting and containing a good deal of information as to the current required by different apparatus and by different circuits, and many problems had been put before the meeting. The information given in the curves and tables would be useful in time to come. He thought that the manufacturers — at least those of caustic copper cells — ought to have something to say in regard to the prices of their cells as worked out.

In preparing the figures of cost of various sources of power in table I, it would appear that the Author had left out the cost of the necessary leading wires from the spot where the supply was given to the place where the apparatus to be worked was situated. If the original cost, the maintenance, renewal and interest charges on these leading wires were taken into account, he thought the comparative costs given would be modified considerably.

Taking the paper and what it purported to tackle, *i. e.*, the power supply, generally speaking the portable accumulator system was advocated. Mr. Thorrowgood had one case of portable accumulators, and was arranging for it to be charged where it was used, from a supply some distance away and thus dispense with the portable duty. He thought that the practice of carrying portable accumulators about was very objectionable, and could not see how it was that the Operating Department of any

railway allowed acid, of the nature of sulphuric acid and water, to be carried about in passenger trains. The question of carrying accumulator batteries of acid cells from one place to another should not be tolerated; it could be avoided. If they had cases where accumulators were wanted at distant points the real solution lay in the conclusions mentioned in the paper, namely, that they wanted a supply at all parts of the line. Even if they did not have a supply all over the line, it would be an economical proposition to run a line and charge the accumulators *in situ* instead of carrying them about. At large places, certainly, portable accumulators were not required, and they had only to remember the price of electrical energy and batteries to see that the best form and the cheapest form of getting electrical power was by having central batteries. All they had to do when there was a central battery and many diverse circuits was to see that the resistance of the apparatus outside was as high as possible and the internal resistance at the battery as low as possible. When there was that in any apparatus — whether at a telephone exchange, or a system of battery power at a large signal box like Waterloo, Clapham Junction, Basingstoke — there was no difficulty about it at all. At Waterloo there was one central battery which provided current for everything there. He had the honour at Clapham Junction to be the first to put in a central battery system which not only provided for all the control circuits, point detection circuits, indicator circuits, etc., from one battery, but also for the track circuits themselves. The problem of providing a central battery system was not, therefore, new, and he was a little surprised that the Author, as a power man, should not have appreciated that. He thought that they should have the pluck of their opinions and try it out. The central battery was the thing to go for. That at Waterloo supplied current for the circuits of the control system, indicators, etc., and for the point detector circuits too. They had an easy means of finding whether the insulation resistance of the system was good or bad, and if it had a tendency to go down, the lineman was there and could quickly put it right. The secret really was *low* internal resistance and *high* external resistance, so as to use up the energy outside the battery, and then the 13 % mentioned in the paper could be reduced. They would of course certainly lose some of the energy of the battery, but they could make it as small as they liked according to the apparatus.

There were many points which could be raised on the paper. He had always advocated that they should not be economical in battery power, because there were two things to think of. One was the working of the apparatus which they wanted to work smartly and with no trouble, the other was that they did not want it too refined, because should certain classes of circuits be connected to earth and subject to lightning discharges, and the apparatus was so fine that one milliampere would bring down the indicator, they might be sure that sooner or later there would be trouble with stray currents and magnetic storms. As the Speaker showed in his paper (1) every circuit all over the country was, some years since, affected by a magnetic storm. They must not be too economical in current, and then the apparatus would work well and not be interfered with by stray currents. That applied also to track circuit work.

There was a great demand for primary cells or something of the kind on railways now that would give out, say, two amperes for a considerable period, perhaps only intermittently, and he put it to manufacturers that that was one of the problems that railwaymen would bring

(1) Magnetics Storms, *Proceedings of the Institution of Railway Signal Engineers* for 1921, p. 105.

them up against shortly, if they had not already done so.

He had not very much faith in local authorities and others supplying power continuously as a railwayman wanted it. He had one case at Hampton Court where the current was cut off for three minutes, and caused a considerable amount of trouble. He saw the engineer and complained, who said « Well, it was only for three minutes ! » He pointed out that there was a stretch of line for so many miles out of service for that period, and it rather opened the engineer's eyes. They could get over that difficulty, and it was always well, in addition to that, to provide oneself with reserve power. For that reason it was not uneconomical to have two sets of accumulator batteries — one discharging and the other being on charge or at rest already charged. In the case the Author mentioned in the first part of the paper — he was a military man and Mr. Thorrowgood was not — he did not agree when it was said : « Under certain military and labour contingencies a general failure of electric supply is possible, but when these circumstances arise, the *importance* of signalling will probably be slight. » He did not agree, because when the military necessity came and trains had to be sent from Aldershot to Southampton, the signalling was of the utmost importance. Even under such conditions if there was a large station like Waterloo — where there were two sets of accumulators — there was such a reserve of power with the central battery system that they could afford to have those labour contingencies, and even military contingencies — which he hoped would not arise. In the case of the general strike, the Southern had no trouble at all, because it had a reserve of power. That was another reason why they should not be too economical. They were found out at such times as that, and, in a very great measure, were judged by the resources provided to meet such conditions. Although it might possibly take a little cost to run the extra accumulators for three or four years without requiring their aid, when the time came it paid over and over again. Two sets of accumulators certainly provided against any failure of the power supply.

That was rather different in the case of alternating current. The supply companies had a set of apparatus with which they charged the mains, and if that apparatus, for any reason at all, failed, everything must fail. In that case they had to provide some subsidiary apparatus, or the power supply people must do so, in order to maintain the supply and give the continuity that was necessary.

He had already referred to the low resistance, and the case of telephones that the Author mentioned on page 789. All that was required there was low internal resistance. Included in that low internal resistance was resistance of the conductor from the battery to the apparatus.

Hand magnetos had been in use for a good many years. Some people, for one reason or another, liked them, but when they did fail, they were a source of trouble. They required skilled attention to put right, whereas a battery only required an ordinary man.

As regards battery power for track circuits, on page 786 the Author said : « Track circuits in inaccessible positions such as those in use with controlled advance section signals or semi-automatic signals, can be fed by portable accumulators distributed weekly or fortnightly by special train. » He would only call attention to the fact that between Basingstoke and Woking, twenty-five miles of line, with four lines of rail track circuited, gravity cells were used. Those gravity cells only required looking after once a month. They could have a primary cell of the gravity type which only required to be looked at by the lineman once a month. A portable accumulator on the other hand has to be taken away every week or fortnight to be charged

and brought back to the place where it was used, and had to go all through the booking arrangements described in the paper. The gravity cell had a lot to be said for it; it was very reliable and efficient and as regards first cost very economical.

He thought that the information given in the paper was well worthy of the Author and of the Institution, and was sure it would be useful. He could not help smiling when the Author asked for perfection, and he supposed that was the way his conclusion No. 12 on page 792 was to be taken. If the Author could find an accumulator like that, Mr. Thorrowgood could assure him he had made his fortune.

Mr. C. J. Cooke appeared that night as an advocate of the primary cell, which generally was at present a pretty lively cause. They were not going to kill it just yet. He was rather surprised that the Author only mentioned two types of cells. He mentioned the Leclanché, which included the carbon-zinc type, but not the gravity (sulphate) cell. The gravity type was very extensively used, and although in many cases it had been replaced by the soda cell, it was still doing very good work indeed, and was likely to do such work for a good many years to come. He remembered two or three years ago arranging for the installation of a set of gravity type cells, giving an output of something like one to two amperes, to work a track circuit nearly a mile long — a single section nearly a mile long.

He did not know whether that circuit was working to-day with gravity cells, but it used to work quite satisfactorily. Although the insulation resistance was only in the nature of about 0.5, he succeeded in getting a train shunt of 0.2. This was with gravity cells, and he did not know that they could get anything better with an accumulator. The particular situation of the battery in that case would have rendered it very difficult indeed to have got accumulators to and from the site. Perhaps the President could say if that particular installation was still in existence. It was working very well in the Speaker's time.

The question of universal batteries for telegraphs had been touched upon. There, again, he thought the last word for the primary battery had not been said. Up to two years ago, an important telegraph office on the London & North Eastern Railway — it was a very busy office, one of the busiest on the system — was worked by one set of No. 1 Leclanché cells on what the Author termed the common battery system, *i. e.*, one common battery was supplying the power for all circuits, the centre of the battery being earthed, and current supplied to each circuit through varying resistances. As an alternative to that many installations had been put in on the universal system, also supplied by No. 1 Leclanché cells, and where the power had been tapped at different points supplying different circuits. A certain advantage in connection with that method was that if they had varying insulation upon the line, due to changes in weather, the battery would accommodate itself to the varying conditions better than if it passed through a resistance before it got to that point. The reason would be readily appreciated by those who had to deal with those circuits.

He had been very interested in the paper; more interested than in many which had been read for some time, and he thanked the Author for the way in which he had brought matters together and put the problems before them. All the problems had to be faced, and they could not lay down any hard and fast rule or one particular method. The primary battery had its uses and would have for some time to come, while in many cases, where power was available, it was more economical to use accumulators.

The PRESIDENT said he would inform Mr. Cooke that the installation to which he referred was still in existence, and working successfully. Also, a stage further had been taken. He had added to the battery increased voltage, and ampere-hour capacity with suitable regulating resistance. In one case, working through a long tunnel, cut sections had been taken out. It costs less to consume zinc and sulphate of copper in a large battery than to pay the additional wages to keep cut section track circuits going. That briefly emphasised the point made by Mr. Cooke. Regarding the question of the universal battery working at a large telegraph office, he had always condemned common battery working, and, for the reasons advanced by Mr. Cooke, did not consider it was as satisfactory as universal battery working.

Mr. G. H. CROOK considered that the paper was too voluminous as not to require comment. He was interested in the Author's fifteen questions and would like to ask, in regard to No. 5, whether he had any information? The Speaker thought at first that it was a mistake, but understood now that it was a serious question, so would like to ask whether the Author had any information, or whether anyone in the research world was working in that direction.

He agreed with the previous speaker that each case really wanted to be decided on its merits. The gravity cell again had been mentioned in competition with accumulators. There was no question that the gravity cell was one of the most constant cells known. The Great Western had a few in use, and never heard about them, which perhaps was the best advertisement, but he was afraid that progress had to be in other directions.

The Author seemed to have a predilection for the petrol generator. That may be all very well, but the Signalling and Telegraph Engineer's province was to do with signalling and telegraphs, and not to manufacture current, and he did not think that as a rule he should manufacture current from primary generators. He had some experience, some years ago, of running some automatic signals off a petrol generator set, and it gave a good deal of anxiety.

Another generator had been mentioned — a development of the telephone generator. That was a hand generator for point operation, which had the advantage of dispensing with the large primary battery to operate points, and was an excellent proposition.

With regard to the common battery system, it seemed that if they used primary cells there was some argument for using the tap system, because they did not use as much battery material. For the common battery system for indicators working on two volts they had to feed through enormous resistances, and practically the bulk of the energy was used in the resistance. The tap system had certain disadvantages, in that so many wires had to be provided, and the battery was used unequally. That could be got over, to some extent, by paralleling the portions of the battery which were considerably used.

He would like to mention the case of alternating current track circuits working with rectifiers. It might be of interest to mention that on the Great Western there had been such an installation working for *eighteen months* with no trouble at all. There was another installation which had been working for a few months, and there the rectifiers had not given any trouble.

The paper referred to a mixture of alternating current transmission system and accumulators. Candidly, he was an alternating current man, and did not care about mixing the two things if it could be avoided. There was some tendency to boost up an alternating current system with accumulators, which could carry on

the work in the event of the power failing, but which complicated the system.

Mr. H. H. DYER drew attention to the statement on page 778 that « during the last twelve years the use of the portable lead-acid accumulator had been greatly extended ». His experience was all the other way; to his mind it had practically disappeared.

The figures in the table for the cost of supply seemed extraordinary. The Author had given a description of a very elaborate system of dealing with portable secondary cells, by which he brought down the cost per B. T. U. to 2 sh. 6 d. He showed frequency of replenishment for 1 000 watt-hours as 4.16, or about 7 d. per recharge. It must be an extraordinarily efficient system to bring it down to that figure. The Speaker had had some experience of the cost of labour, and it was very much more than would be expected from the figures given. Then, again, the figures for the zinc-copper oxide cell with caustic-soda — 30 sh. 6 d. per B. T. U. He had no correct figures with him, but the figure given was at least twice as much as it ought to have been. It affected the cost greatly whether they dealt with the recharging themselves or whether they scrapped the whole thing and bought new recharges. He thought that must be the cause of the difference.

On page 775 the Author said that the figure for the portable lead-acid accumulator included electricity, labour in charging station, and handling and transport to and from the lineman, but he did not say that it included the lineman's time in changing the cells, and that was a very big item. There was also the question of an allowance for depreciation of the cells — that was another big item which should go on to the 2 sh. 6 d. The Speaker's figure for soda cells included all labour charges, also the renewal of all parts which depreciate every time the cell was recharged. There was no depreciation really, because it was allowed for every time.

Speaking of the soda cell the Author said : « Besides increased first cost, more labour in attendance and greater accommodation space are required. » That seemed very strange. One great advantage of the soda cell was that from the time it was made up, to the time it was recharged, it did not want looking at once.

On page 777 the Author remarked : « When power is required in any amount, say more than 50 watts, it is cheaper to instal a battery of 120 ampere-hour 2-volt portable accumulators. » Would he instal those on low voltage distant signal machines? Those took more than 50 watts in many cases.

On page 790 it was remarked that with caustic soda cells for track circuit feed work « a high train shunt is not always possible of attainment ». What was the Author's idea of a high train shunt ? The Speaker's experience with caustic soda cells was an average of about one ohm, and that was quite satisfactory in his opinion.

Mr. C. M. JACOBS said that there was a little misunderstanding with regard to the portable accumulator. As the Author had pointed out, the portable accumulator was much cheaper for the type of work for which it was used than any other type of cell. The portable accumulator, however, was more liable to failure than other types of batteries. The Great Western had also had some rather serious fires with accumulators, and they were now gradually disappearing from that company's system.

Mr. F. Towell would like to know how the Author arrived at the outputs stated for the large dry cell. An output of 204 ampere-hours was given, but it did not state the limit of effective voltage, or efficient voltage, so it was rather difficult to measure the cost per 1 000 watt-hours.

He believed the railway standard for those large dry cells was somewhere in the neighbourhood of 270 ampere-hours, and that being so, he thought the Author would find the figure of 22 sh. 6 d. would be very much reduced. As a matter of fact there were cells which gave something in the neigbourhood of 300 ampere-hours which would reduce the cost to about 15 sh. or 16 sh., but, of course, the difficulty was that there was a railway specification and manufacturers had to make cells to that specification — in other words they must not make cells too well.

Then another point was the zinc-carbon cell of the Leclanché type. The Author gave a figure of 30 ampere-hours. The Speaker took it that the No. 2 size was referred to. He could not say for certain, but had the No. 2 sacs been used they would probably have found the output somewhere in the neigbourhood of 50 ampere-hours. Possibly the No. 1 would give 80, probably more. This cost figure therefore was rather higher than it should be.

He was afraid the lead-acid accumulator had been rather flogged that evening. He took it that in the 2 sh. 6 d. mentioned there was no charge for transport one way or the other.

There was a point on page 777. He believed it was the system on some of the railways that when a cell came back as being completely exhausted the cell was re-constructed and put on a local circuit with a fluid excitant. Some useful service was still obtained from the cell and it was, not as indicated, actually thrown away.

He presumed that on page 788 the words « Different sizes of cells must be kept together », should be « *similar* sizes of cells should be kept together ».

On page 791 the remark was made « It is interesting to note that to obtain 120 volts from a battery of Leclanché cells, sufficient cells have to be included in the battery to make up for the loss of about 18 volts due to internal resistance ». Of course it all depended on the type of cell used. The porous pot had a certain internal resistance, and the sac element had a lower internal resistance. The No. 1 and the No. 2 differed of course in that respect.

Regarding the question in conclusion « Is it possible to design dry cells which will keep and stand in use indefinitely without any deterioration ? » He presumed that was on a par with No. 12 in an attempt to obtain the millenium as regards cell manufacture. The point he would like to emphasise was that if the railways would let manufacturers make good cells, they would make them but if they were restricted, they could not help themselves.

Mr. J. Boot thanked the meeting very much for giving the contractors a chance. Following on the last Speaker's remarks, when he (Mr. Boot) was on the railway, Mr. Towell occasionally came to see him in regard to the specification which laid down that on test the Leclanché cell should be discharged through 10 ohms resistance. What circuits were there which were going to require that? If they had a standard specification for those cells to discharge through 10 ohms, they were putting down something which there was no use for. As Mr. Towell had said they were asking for something which was too good for the work.

He was rather interested in reading through the Author's summary of the possible sources of supply. There was one source of supply he believed the Author himself used which was not mentioned, and that was the thermo-electric couple. The Great Western Railway, at any rate, bought two, and he believed they were rather successful. It would be interesting to hear the actual results of the work. They were put in the station master's office over a gas jet, and used to operate track circuits.

Another question was in regard to

standard voltages. There were a number of primary battery operated point and signal machines in use to-day, and they were ordered, usually, for 12, 20 or 25 volt circuits. As a matter of fact when those fittings got out on to the line the voltage of the battery had to be adjusted so that the voltage across the motor was read when it was running, *i. e.*, usually they found a 20-volt motor running on a battery giving 30 volts on open circuit, so that the requisition should always state the voltage across the motor when it was running.

There was a point the Author raised with reference to the relation between the safety of the circuit and the current consumption. He quite agreed with Mr. Thorrowgood that they were cutting down the limit of safety on some circuits, particularly relay circuits. Relays were now being constructed operating with 3 to 4 milliamperes, and it was questionable whether safety was being sacrificed for the sake of saving current.

The Author asked in question No. 3 « Will electrical signalling apparatus of all kinds be designed to operate on say 24 or 110 volt direct current? » He took it he meant that they would have two separate voltages of 24 and 110. Why had he struck on these two voltages? If he was going to have two, one might be a multiple of the other — charge in series and discharge in parallel.

Then, the paper in paragraph 5 asked : « Can a static direct current to direct current converter of good efficiency be produced ? » He hardly saw the necessity for that, because the above arrangement solved the problem.

Mr. C. Silcock agreed with Mr. Towell about the cost of current from the primary battery. So much depended on the size of the unit — primary batteries could not be compared with 100-kw. generating stations. He did not know if railway people realised what wonderful batteries they were getting. It was like the locomotive power question, there was no finality. They no sooner got just the right thing and the locomotive required, than the trains were made longer and longer.

With regard to the points in conclusion, so far as No. 8 was concerned, there had been a very considerable attempt to standardise batteries. There was a railway national specification and he thought they might now say that that had been done.

One point he would like to make quite clear. The Author complained that he got too much scrap zinc, but in dealing with the primary cell it all depended on the rate of discharge. Manufacturers had to give enough zinc to ensure that the cell would not bleed, but it could be made to bleed if the current was taken out slowly. As a rule, however, current usually was taken out much too rapidly, and consequently the cell was used up in a very short time, and the zinc left over.

With regard to No. 11, while it could not be claimed that dry cells, like port wine, would keep in stock and improve with age, it could be said that they would stand in stock any reasonable time.

Mr. T. Austin would like to ask what percentage of the total number of accumulators in use on the Great Western were in the repair shop at any one time? Also, is not the question of the fire risk in charging these celluloid cased accumulators a very considerable one? Were they to assume that the Author's opinion of the shortcomings of the accumulator were set out in question No. 12 ?

He came across another possible source of supply the other day. A patent was recently taken out for a method of generating electricity by the passing of a train, making use of the depressions of the rails. The apparatus was apparently designed specially for lighting country stations, but he suggested that that meth-

od might also be used for supplying current for signalling purposes.

He thought that the Author had not done justice to the caustic soda cell. It had been put down in the table as one of the most expensive cells, but it required very little labour in attendance. His experience with caustic soda cells was that they did not need so much in attendance for recharging as many other cells.

With regard to the table, he thought the figures ought to be given with some qualification. The broad statement of approximate cost per 1 000 watt-hours were not comparative at all.

Mr. R. M. Sinha wished to mention that in his recent visit on the Continent he found a general use of portable accumulators on the German State Railways. Indicators, clocks, Morse sounders and keys, etc., in a station were all fed by a centre battery system. The accumulators were sent to the charging depot in rotation.

Mr. T. C. Elliott would say that the questions the Author put at the end — and the one which took his attention in particular, was question No. 12 — were not so hard to answer if they eliminated the things which did not matter, and the things which could be ruled out altogether, such as the dropping of the cell. Was it necessary to drop the cell at all ? No other apparatus was dropped about, or, if it was, the man got into trouble. He did not think in a good article they needed every part to be visible. They did not ask for a watch to be put in a transparent case, and it possesses far more delicate works than an accumulator. Testing the gravity of the acid would tell the condition of the cell. With regard to leaving it standing idle he did not think it was fair to ask that a battery stand idle for long periods without being recharged; they would not ask a hungry man to stand idle without a meal. It was the case, however, that accumulators could be left to stand for much longer periods in an idle condition when fully charged, or partly charged, than was generally expected. He had known of a case of a battery being overlooked for eighteen months without any loss.

Coming to the point of the testing of the cell, it should be noted that mention was made of the specific gravity of the acid being a guide. This was so, but the rate of discharge must be taken into consideration. In a recent test, a battery of 20 ampere-hours lasted for 450 hours at 0.06 ampere. At the end of that time the voltage still remained at 1.9, which would lead one to believe that the cell was capable of doing useful work. So it was, but only at that rate of discharge. The gravity of the acid was little more than that of water. The rate of discharge must be taken into consideration.

The skilled attention said to be required in charging accumulators was not as terrible as it was made out to be. He had a case brought to his notice where a plant was in charge of a gardener, who had possibly not learnt more than simple instructions and was able to read the hydrometer and the voltmeter, but who kept a battery going for ten years without any trouble. In another case a woman was in charge of a large battery, and got on very well indeed for ten or twelve years. Skilled attention was only required when something went wrong; otherwise there was no expert attention required at all.

Mr. A. B. Wallis thought the table No. 1 very interesting. For many years it had been his practice, in reporting on new types of cells, or new sizes, to give the cost per B. T. U. They must have some sort of comparison, and if the conditions of discharge were similar it was a fair comparison. On going through these figures he agreed with Mr. Dyer that for the lead-acid portable accumulator the charge was rather low. His own experience gave a much higher rate than that.

It was a fact concerning soda cells,

that with 300 ampere-hours soda cells discharging at normal track circuit rates, it was possible to maintain the battery indefinitely at a cost, at present prices, of approximately 18 sh. per B. T. U.

No one had mentioned the windmill plant. That he believed was a practical proposition, although he did not know of any in use on any British railway. Some years ago the Midland railway went into this question. After looking through twenty years of anemometer readings, the most striking feature was the constancy of the wind, that is over periods of say three months. Day by day it was the most inconstant thing known, but over any lengthy period it was one of the most constant.

Mr. W. Challis would like to express his thanks to the manufacturers of both batteries and signal and telegraph apparatus for helping the Signal Engineer through his most difficult duties.

The central battery system where it could be employed was the better way, but in cases he had in mind, where there were block working and apparatus, somewhat remote from the source of supply, such as outer or advanced signals, or distant signal repeaters and treadles, it did not seem to be economical or practicable to have a central battery supply for them. The source of supply, so far as the signal repeater or treadle is concerned, should be at the remote end of the circuit.

With regard to accumulators for track circuits, he thought there had been sufficient said that night to show that caustic soda cells were much better and cheaper than the accumulator, and, in regard to train shunt, he would like to endorse what another speaker had said that one could obtain as good, or even better, shunt than with an accumulator.

Another source of supply was from power mains supplied by outside firms. He had had some years' experience of supplies from various electrical firms, and thought that they had done very well indeed. He could not say that they had not failed, because during a period of about ten years on the Metropolitan he had had a failure for a few minutes only on three occasions. On the other hand there was the possibility of failure, and as Mr. Thorrowgood had pointed out, if it did fail, it meant loss of time and chaos in traffic operating. Thus the power supply should be in duplicate, but with power supply companies, the chance of failure was very remote indeed.

With regard to the remote operation of points — 1 000 yards or more away — he was still of the opinion that the hand generator was a good thing, and would prove itself in years to come.

On an electrified route there was one difficulty that most people came up against where they had continuity of supply, and that was at remote places where electric direct current traction was in use, and the Traffic Operating Department required alternating current track circuits, and there was no supply company to give the current needed. He would suggest to manufacturers that there was a field there where they could help the Signal Engineer by supplying a 0.1 to 1 kw. in a cheap manner. He would just refer to Mr. Crook's remark when he said that that was not the Signal Engineer's job. He would like to ask whose job it was, if there was not an electrical generating station near?

Referring to paragraph No. 3 in conclusion; if electrical signalling apparatus of all kinds be designed to operate on 24 or 110 volts, why limit it to 110 volts ? If they had a power supply at hand, and had a set of points or signals to work, why not go to 220 volts and so save copper ? He mentioned that because he thought where possible they should take from the line supply to move the points, and the supply should come from the lever itself and not locally.

The President observed, in regard to

battery signal machines, that there was one system used in earlier days to get heavy output, *i. e.*, primary cells charging a floating battery of small accumulators, which took care of the peak load when the signal worked to the « off » position.

The current requirements of the Signal Engineer and the demand from primary cells have been increasing almost month by month; from 2 to 3 amperes for the signal machines and 4 to 5 amperes for point machines. The London & North Eastern Railway had recently made extended trials with the air depolarise type of primary cell. The larger size cell will supply about 4 amperes, and operate point machines quite successfully in 10 to 11 seconds. Further demands had been made upon the Signal Engineer to operate points in five seconds, and this had been done, but the primary battery was doing it with rather a struggle. He felt, as some speakers had said, that they put more on the battery manufacturer than he could give. Although he thought that eventually primary battery manufacturers would be able to produce a multiple unit cell containing the sac type element, combined with correct design of zincs and containers, which would give excellent service in special cases. Endeavours to find solutions for difficulties they had to contend with, and to advance practice in connection with signalling on railways, must continue until they had standardised principles as well as apparatus. The supply of power for certain classes of signal engineering would continue to be met with the primary battery.

The difficulties prevailing 15 to 20 years ago in getting Leclanché cells which would stand up to the strain indicated by diagrams 5 and 6 had been overcome, and manufacturer's representatives present might remember the difficult times passed through at that period, but which were overcome, and the manufacturers had had time to develop cells to meet special requirements. For instance, the caustic soda cell had held a very strong position. The air depolarise cell had overtaken it, and was meeting conditions for new apparatus better than the soda cell. It had a higher voltage to start with, which was maintained throughout its useful life.

Another speaker remarked on the clause in the specification which stated that the tests for primary cells must be made through 10 ohms. A lot of people could never understand that. One reason was that the purchasing agent requested the user on the railway to let him know within a fortnight whether he could certify the invoice for a given quantity of cells delivered. It was impossible to put primary cells through a test whereby they could reasonably satisfy themselves in a fortnight unless they put them through rather drastic treatment.

Mr. E. C. Deacon (written contribution) said that the part of the paper which perhaps interested him most was that dealing with the « Roundabout » method of charging. It was stated on page 789 that commutator ripple was not heard if the cells of a 24-volt common battery on a common battery exchange be charged by this method whilst at work. That struck him as remarkable seeing that receivers were so sensitive to an alternating current hum, from whatever cause.

Turning to figure 6. — That system was of course wasteful on account of the resistances, and emphasized the need for standardization of apparatus and voltages of supplies. Was there any possibility of a heavy demand on one portion of a Universal battery, as in figure 5, being sufficient to produce a drop in the cells, due to their internal resistance of sufficient magnitude to affect other circuits appreciably? It seemed to him that, when the cells had been on circuit for some time, such apparatus as block instruments was bound to flicker, unless over-voltaged in the first instance, hence another source of waste.

The arrangement shown in figure 8, on the left-hand side was undesirable unless some means was provided for placing a constant check on the stand-by battery. Otherwise it might not respond when required.

With regard to table I. — The Leclanché type cell was rated at 1 volt average. On page 790, the voltage curve is given as 1.5 volts — 0.9 volts. That, presumably, was the useful part of the curve and was not in agreement with the table figure of 1 volt average. Similar remarks applied to the alkali cells. He felt that the actual cost of current as given in table I was but a very approximate guide to the value of a cell for a particular job, since so many other facts must be taken into consideration. As an example : the case of the caustic soda cell might be cited. In spite of the cost of the current obtained from it, it was, he understood, the most popular cell in the United States.

At the foot of page 777 it was stated that dry cells must be thrown away when discharged. He could not imagine that that course was pursued on many lines in these times of economy, especially as it was admitted in the next paragraph that quantities of zinc remain.

With regard to the « Windmill » proposal, it seemed that much experimental work was necessary in that connexion before such plants could be used to any extent with any degree of confidence.

He thought nowhere did the Author mention a higher voltage than 24 volts for use in signal boxes, except where 110 volts was installed for power frames. But several selective telephones required higher voltages each side of earth which necessitated a large number of primary cells.

It would appear that in most cases they were putting the main supply at the wrong end of the circuit if common batteries were used. Unless the feeds were on a separate route, there was a danger of contacts causing false « clear » indications.

With primary cells in use, a lineman knew that he must visit regularly, but with accumulators, running perhaps two months as suggested, there was more danger of the visits being neglected. That applied particularly to isolated locations. Perhaps it was a case for the psychologists, but nevertheless, it probably existed.

THE AUTHOR'S REPLY.

(Communicated.)

The large number of questions raised in the course of the lengthy discussion made it impossible in the time available to reply verbally to the majority of them.

The written replies and comments on each speaker's remarks are given in the order in which they were contributed.

Reply to Mr. Thorrowgood.

In preparing the cost per B. T. U. from various sources of power, it was assumed that leading-in wires would be provided for whatever source of power was employed, whether it be a battery of primary cells or a local power supply. The inclusion of the original cost, maintainance and renewal of such wires does not in consequence enter into the cost of energy per 1 000 watt-hours.

No particular source of energy was advocated, but attention was drawn to the advantages and disadvantages of various sources available.

The transport of a few portable accumulators was quite likely to be unsatisfactory, but when many thousands were dealt with special carrying chests being provided, no particular difficulty need be experienced. The rough treatment accorded the chests was the worse feature.

The charging of 2-volt accumulators *in situ* was an expensive matter, owing to the provision of transformer or con-

version plant being necessary and could not be justified in most cases.

The use of common battery systems is referred to on page 784 and illustrated by figure 6.

It is gathered that the supply from local authorities cannot be generally considered as sufficiently reliable for signalling purposes.

The military contingencies referred to were those arising when invasion took place or a power station and transmission lines were put out of action by artillery or air-craft bombardment near the front line.

With regard to the use of gravity cells on 25 miles of four-track main line, without knowing full technical particulars as to the number of track sections, it was suggested that an important saving in labour and material would be obtained by the use of 2-volt 120 ampere-hour portable accumulators, charged at a carefully designed and organised charging depot and distributed by an engine and van, say, once a week.

The gravity cell had been gradually dispensed with in many places, because it was messy, was unsuitable for open circuits and was costly in zinc and copper oxide, except when used on the lightest work.

Reply to Mr. C. J. Cooke.

The modern primary cell was entirely suitable for use in a large number of cases, but the Daniel cell could not be considered as particularly popular. The study of the advertisements of battery makers confirmed this, as reference to them was practically absent.

Without knowing all the circumstances connected with the interesting example of the application of Daniel cells, it would appear difficult to understand how the situation where they were in use was such that while men could get at them when renewing them (which would be a lengthy job) portable accumulators could not be taken to and from the place.

With regard to the working of large telegraph offices from Leclanché cells, in a similar case known to the Author, an installation of 10 ampere-hour stationary accumulators with a small charging plant was put in, to replace hundreds of primary cells, wet and dry, and resulted in between £100 and £150 per year being saved in maintenance, the common battery system being adopted.

Reply to Mr. G. H. Crook.

The need for a static direct current to direct current converter of good efficiency was becoming increasingly felt. In many places a 200-volt direct current supply was available, but to reduce it to even 24 volts, necessitated the use of a rotary machine of some kind with its consequent liability to go wrong if not attended to at frequent intervals. It should be understood a perpetual uninterrupted supply from such a converter was referred to.

There must have been some serious defect in the Daniel gravity type cell, when it was superseded by the Leclanché and the dry cell. The affection expressed for the Daniel cells, made the proverb « Absence makes the heart grow fonder » seem singularly appropriate.

It was submitted that the Signal Engineer knowing fully the requirements of a supply of power for the circuits for which he was responsible was the man most suited and fitted to provide and apply such a supply. This of course would not refer to large general power stations, giving a signalling supply in addition to large lighting and traction loads.

Reply to Mr. H. H. Dyer.

During the last twelve years the Author had been closely associated with a very large increase in the use of the portable lead-acid accumulators.

The cost of recharging portable accu-

mulators in large numbers, say 2 000 per month, works out at the figure given in table I. As stated in the paper this included electricity, which was a very small proportion, labour in the charging station, and handling and transport to and from the lineman, rail transport not being charged for. The lineman's time changing the cell is not included as the lineman was on duty and if he was not doing that he would be doing something else, perhaps less important. In any case it did not work out very much in most places.

The cost for the zinc-copper oxide cell was based on the prices given by the suppliers of the complete sets of renewals.

As mentioned, a depreciation allowance must be taken into account, but it cannot be included in the cost per B. T. U. It must be added to a yearly bill.

The Author claims that the soda cell, output for output, was more costly and needed much more space than portable accumulators.

When thousands of soda cells had to be maintained, the labour costs in renewal and examination work were heavy.

Three 4-volt 40 ampere-hour portable accumulators in series were best for busy battery signal machines, but dry cells were preferable for lightly worked circuits of this kind.

It was a generally accepted fact that a 2-volt cell enables a higher train shunt to be obtained, than with a 0.65-volt cell, other conditions being equal.

Reply to Mr. F. Towell.

The outputs of the large dry cells were supplied to the Author by a large manufacturer of these cells and have been confirmed as reasonably accurate. In column 1, table I, was given the « average voltage per unit cell ».

The figure for the 30 ampere-hour Leclanché type cell working under the conditions given in the table will be found to be a good approximation.

Manufacturers of cells sometimes complain that they do not know the conditions under which their cells have to work and what was required of them. This paper was an attempt to answer their questions and when the answer was not what was expected it was hoped it would however be taken seriously.

Reply to Mr. J. Boot.

The Thermopile was an attractive piece of apparatus, on paper, but would not stand up to continuous use for more than six months or so.

The voltages of 110 and 24 were chosen, as the former was largely used for power signalling and the latter for telephone exchanges.

Reply to Mr. T. Austin.

The number of portable accumulators out of use for repairs, examination and testing was at most less than 5 %.

The risk of fire with celluloid accumulators was the most serious defect they possessed. If manufacturers could solve this problem they would render a great service.

The figures given in table I were given with qualifications and full electrical conditions. The figure for the caustic-soda cell was based on information obtained from the suppliers of them in this country.

It was submitted that when it was desired to compare the results obtained from various articles, the result required must be the same in all cases.

The result required was 1 000 watt-hours and the cost of and the conditions necessary to obtain it were given in table I.

Reply to Mr. R. M. Sinha.

The Author was greatly obliged to Mr. Sinha for the information regarding the extensive use of portable accumulators for railway signalling purposes in Germany.

Reply to Mr. T. C. Elliott.

Question 12 was based on practical experience, and unfortunately, when portable accumulators were sent by train in wooden chests, they were liable to be actually dropped by porters and others who handled them. It was agreed that transparency was not absolutely essential if the vent holes were of good size to allow of inspection of the interior. But could a case be produced having the same strength as celluloid and yet keep within the dimensions given in figure 1?

If it was possible to eliminate the danger due to inflammability, and the tendency to a short life due to plate troubles, the portable accumulator which complied with the conditions laid down in question 12, would be very seriously considered owing to its important electrical and economic properties.

It was gratifying to realise that accumulator makers were seriously attacking the problems of long idle periods, short first charges and other difficulties with considerable success.

Reply to Mr. A. B. Wallis.

In connection with the figure for the portable accumulator, it applied as stated, to plant charging large numbers at once. For smaller plant dealing with 800-1 000 per month, the cost would be about 3 sh. 6 d. per B. T. U.

The figure for the soda cells was not based on the wholesale purchase of caustic soda, oil and zinc and the treatment of the copper oxide elements, but on the cost asked by the suppliers for renewals with a small addition for labour.

Reply to Mr. W. Challis.

It was not agreed that the caustic soda cell was cheaper than the portable accumulator for track circuit feed work. Assuming a track feed voltage of 0.65 was accepted as sufficient in place of the 2.0 given by an accumulator; to supply 25 track circuits, in one year it would cost approximately for soda cells £23 and portable accumulators £17, allowing a depreciation figure for the latter.

If the battery of soda cells had to give 2 volts, the figure for them would be about £70 per year.

Reply to Mr. E. C. Deacon.

The voltage figures referred to were in the table I the « average » and on page 790 the extreme limits, both being reasonably correct.

Reply to the President.

The kind reception given to the paper was greatly appreciated and the discussion had more than justified its submission. It was hoped that the points brought out in the 15 questions would be seriously considered as their satisfactory solution would result in important economies and even better performances by signalling plant.

Many matters of importance had had to be treated briefly and members would be rendering a valuable service if they would prepare papers dealing in an exhaustive manner with them.

The assistance given the Author by various firms was gratefully acknowledged.

[016 .385 (.494)]

Library Organisation on the Swiss Federal Railways,

By G. HARCAVI,

RAILWAY DELEGATE TO THE INTERNATIONAL INSTITUTE OF THE SCIENTIFIC ORGANISATION OF LABOUR AT GENEVA.

Figs. 1 to 5, pp. 808 and 809.

(*Revue générale des chemins de fer.*)

A library, containing works on technical, economic and legal subjects has been in existence for some considerable time at the Headquarters of the Federal Railways at Berne.

When the administration of the Federal Railways was reorganised in 1923, the library was also brought under new regulations.

All works on special and general subjects belonging to the Federal Railways, even when kept by the different departments and not by the library, have been included in the catalogue of the new Central Library.

This date coincided with the appearance of the review « *Bulletin des C. F. F. — Nachrichtenblatt der SBB — Bolletino delle SFF* » as published by the Headquarters of the Federal Railways.

The Federal Railways has undertaken to exchange its review with Swiss and foreign periodicals on a wide scale. As a result, the annual collection of special periodicals, to which the Federal Railways has subscribed for years, has been enriched by additional reviews. This collection now includes 200 weekly, fortnightly, monthly, quarterly, etc., reviews.

In order to be able to make use of the mass of documents which accumulates in all these publications, the Central Library at once starts to sort them out. The special, thorough, and painstaking examination of the periodicals as organised at the Central Library deserves mention.

All articles, notes, and investigations of technical, economic, or legal interest in the railway field are indexed on small cards.

These cards measure 125 mm. × 175 mm. (4 7/8 × 6 7/8 inches), the size adopted by the International Institute of Bibliography at Brussels and by the American Librarians' Association. Many years' experience has shewn that this is the most useful size to hold the required information.

Each card gives the following information about each article indexed (figs. 1 and 2):

1. The year of publication;

2. The decimal classification of the subject matter (Dewey System, as adopted by the International Institute of Bibliography as the universal system), and shewing :

The main class of science;

The division of the special scientific branch;

The group sub-division of the particular questions;

The section indicating the particular features of the article;

The sub-section giving particular points of the article;

1926	385 .5 (44)

REVUE GÉNÉRALE des CHEMINS de FER

N° 6, Juin, p. 427.
N° 1, Juillet, p. 3.

GIRARD, Joseph. — Une enquête démographique sur le personnel de la Compagnie du Chemin de fer du Nord. 10 000 mots et fig.

Fig. 1 — Card for a signed article.

1926	621 .33 (09) (494)

CHRONIQUE DES TRANSPORTS

N° 2, p. 28.

Historique de l'électrification des Chemins de fer fédéraux suisses. 800 mots.

Fig. 2. — Card for an anonymous article.

385 .114	**LEROY, Thérèse.**
Eq. 337	Essai mathématique sur les prix de revient des transports par chemins de fer. *PARIS, 1919.*

Fig. 3. — Card for a book

Readers are requested not to keep
the periodicals more than three days each.

After circulation, the publication is to be returned to :

Nos.	Messrs.	Department

Fig. 4. — Passing on slip for a review on its first circulation.

2nd CIRCULATION.

Periodical ....

Nos.	Messrs.	Department	Received	Sent on

Quick return to Library.

Fig. 5. — Passing on slip for a review on its second circulation.

3. The name of the periodical:

The date;

The number and volume in which the article in question is to be found;

The page on which the article is to be found;

4. The name of the author, if any;

5. The title of the published article;

6. The number of words and illustrations.

The system adapts itself in particular to the classification of articles according to their text, and also facilitates the classification of the whole of the cards dealing with the different branches of railway science.

In fact, this system gives the advantages of a methodical classification together with an easy way of bringing together all the most specialised and most closely related subjects.

The uniformity and unity of the method enable the bibliographical sources to be utilised rationally : the up-to-date simplicity of the method and of the very system itself facilitates scientific investigations into railway matters.

Two indexes : — *a*) subject index; *b*) alphabetical index — are used at the Federal Railways Library as the bases of the research.

Subject index. — This index is used to assist in making an enquiry according to the numerical order of the decimal classes, divisions, sub-divisions, sections and sub-sections (1).

Alphabetical index. — This index is used to facilitate an enquiry by a classifying word or name (2).

(1) See *Bulletin of the Railway Congress*, November 1897 : « Bibliographical decimal classification as applied to railway science », by L. Weissenbruch.

(2) See *Revue générale des chemins de fer*, 1884 vol. I, p. 570; see *Bulletin de la Société d'encouragement pour l'Industrie nationale*, June 1896.

Books are also entered on cards (fig. 3), the same information as for articles in periodicals being given, duplicate cards being used. For this reason there are two central single subject card indexes which shew side by side the books wanted, either according to the decimal classification, or to the alphabetical list of authors' names.

The collection of single subject books and works of the Federal Railways now contains 20 000 volumes.

In the whole of the card indexes (single and multiple entry cards) there are 100 000 cards with extracts from the most important of the publications in question.

As soon as the current periodicals have been gone through, the papers are circulated.

A special table shews how the periodicals are to be circulated through the Headquarters and regional offices, so as to ensure the section concerned automatically receiving in good time all information that may be of use to it.

There are two ways in which the periodicals are circulated in the Swiss Departments :

The first enables the Directors, General Secretaries, Chief Engineers, Engineers, Heads of Sections, etc., to note the articles that interest them. This circulation is quick and takes a few days only, after which the papers are returned to the Central Library.

The slip attached to the periodical (fig. 4) enables the librarians to arrange the second circulation during which the papers remain in the hands of the staff rather longer (fig. 5), so that the staff may consider any questions that affect them more carefully and take any notes they consider necessary.

When the second circulation has been

completed, the periodicals are returned to the Central Library where they are kept.

These modern methods of scientific research through the Press and special literature have already been found of great assistance to the Management of the Federal Railways, which attaches great importance to them.

The saving in time, the accuracy, the large amount of information, and above all the speed with which it is obtained, are of very real value. Furthermore, this scientific thoroughness and this definite centralization of enquiries and studies form a good ground for the methodical development of the scientific spirit in the organisation of the railway system.

MISCELLANEOUS INFORMATION

[628 .112 (.6 + .8 + .94)]

1. — Railway gauges in Australia, South America and Africa.

A brief analysis of the conditions in the three Continents concerned, together with tables showing the approximate mileage on different gauges, and an indication of the possibilities of unification.

(*The Railway Gazette.*)

While the railway gauge problem has been solved in several countries, notably in Great Britain, the United States, Canada, and parts of Europe, there still remains much to be done in the newer countries where, for one reason or another, railways have been developed on different gauges. In many cases a change in gauge was adopted mainly for political reasons, while in others the gauge to which the railways were laid was decided upon in accordance with the economic conditions obtaining at the time. But in every case such a policy must be disastrous. It has been proved in Australia, South America, India and Africa that railways first developed to serve particular interests in locations far distant from others have, in the course of time, been brought together on the same railway network, albeit on a different gauge, and as a result tremendous expense and considerable delay have necessarily been involved in the transit of passengers and freight. It may, therefore, be laid down as an axiom that in no land, however expansive it may be, should the railways be laid on different gauges, nor, now that the train ferry enables rolling-stock to be carried from one railway to another with expedition and safety, should railways in any countries separated by comparatively narrow stretches of water be laid on different gauges.

The gauge problem is, in fact, one of the most difficult with which civilised nations have now to deal in regard to transportation, and as development in the broadest sense means transportation, it is of vital importance that this question of gauge unification should be in the forefront of every programme designed for expansion of the countries' resources. During the last two or three years we personally have experienced many of the difficulties, complications, delays and inconveniences inseparable from the adoption of different gauges on railways operating in the same territory, and as a result are more than ever convinced that gauge unification, despite all political complications, is essential.

In recent travels we have been over the railways of Australia, the United States, Canada, and the various Republics of South America, and have been struck with the difference in practices. But we have been even more concerned with the difference in gauges. The United States and Canada have, of course, the standard railway gauge, as adopted in this country, while in Australia the Trans-Australian Railway, together with New South Wales, also adopt the standard gauge. Victoria and South Australia, on the other hand, mainly use the 5 ft. 3 in. gauge, the latter, however, having a large mileage on the 3 ft. 6 in. gauge, which is also that adopted entirely in Western Australia, Queensland, Tasmania and New Zealand. In this connection it may be recalled that the recent Gauge Commission definitely recommended that the gauge for Australia should be the 4 ft. 8 1/2 in., and while there are indications of a slow movement towards unification on that basis, recent developments, particularly in connection with the North-South Railway, do not lead to the hope that unification on the standard gauge will mature within the near future.

RAILWAYS OF SOUTH AMERICA, SHOWING MILEAGE ON VARIOUS GAUGES.

COUNTRY.	Area, square miles.	Total railway mileage.	5-ft. 6-in. gauge.	5-ft. 3-in. gauge.	4-ft. 8 1/2-in. gauge.	3-ft. 6-in. gauge.	Metre (3-ft. 3 3/8-in.) gauge.	3-foot gauge.	2-ft. 6 in. gauge.	2-foot gauge.	Various gauges.
Argentine	1 100 000	23 728	13 786	...	1 879	...	7 323	...	...	...	740
Brazil	3 300 000	19 205	...	1 130	...	...	17 305	...	460	310	...
Bolivia	708 000	1 449	...	...	...	...	1 315	...	96	...	38
Chile	290 000	5 960	1 950	...	437	276	1 755	...	936	...	606
Paraguay	62 000	517	...	...	274	...	48	...	...	...	195
Peru	532 000	2 081	...	...	1 208	22	15	315	...	41	480
Uruguay	72 200	1 654	...	...	1 654	...	...	...	...	...	...
Columbia	441 000	1 428	...	...	...	18	170	1 240	...	...	...
Venezuela	394 000	661	...	...	...	197	40	33	...	136	255
Ecuador	220 000	413	...	...	...	280	...	...	40	...	93
British Guiana	90 000	79	...	...	60	19	...	...	...	...	...
Dutch Guiana	54 000	108	...	...	...	...	108	...	...	...	...
	7 263 200	57 283	15 736	1 130	5 512	812	28 079	1 588	1 532	487	2 407

In South America, speaking of it as a continent, the gauge problem is intense, as at the present time there are railways laid on eight different gauges. Of the total railway mileage over 50 % is on the metre (3 ft. 3 3/8 in.) gauge, while, 27.5 % is on the 5 ft. 6 in. gauge and 10 % on the 4 ft. 8 1/2 in. gauge, the other gauges in use being the 5 ft. 3 in., the 3 ft. 6 in., the 3-foot, the 2 ft. 6 in., and the 2-foot. It is true that, broadly speaking, Brazil has adopted the metre gauge, while the Argentine, so far as the principal trunk lines are concerned — always excepting the Corboda Central and Central Northern Railways, which are on the metre gauge, and the lines running north to Paraguay, on the 4 ft. 8 1/2 in. gauge — are on the 5 ft. 6 in. gauge. In the other Republics the railway gauges are variable. Uruguay, with its 1 654 miles of track, is exclusively standard gauge, while Peru, with 2 081 miles of track utilises gauges ranging from the standard to the 2-foot. Chile has five railway gauges ranging from 5 ft. 6 in. to 2 ft. 6 in., while Bolivia is more or less a metre-gauge country. The northern Republics and territories vary between the 3 ft. 6 in., metre, the 3-foot and 2-foot gauges, while British Guiana has a short section on the standard gauge.

It is, of course, quite understandable that the conditions under which these railways were laid down led to the adoption of a gauge which, in the opinion of those interested, would most economically and efficiently meet the need for railway transport, but in the long run there is no doubt that many of these railways will be connected and the troubles arising from break of gauge will then become pronounced. At the present time Uruguay and Brazil have to transfer all their traffic between the 4 ft. 8 1/2 in. and metre gauges, while on the other side the Argentine State Railways and the Central Argentine, in connection with international traffic, have to transfer between the 5 ft. 6 in. and metre gauges at Tucuman. Another break of gauge point occurs at Mendoza where traffic is exchanged between the 5 ft. 6 in. gauge of the Buenos Ayres & Pacific Railway and the metre gauge of the Transandine, and, similarly, at

RAILWAYS OF AUSTRALIA, SHOWING MILEAGE OF VARIOUS GAUGES.

STATE	Area, square miles.	Total railway mileage	5-ft. 3-in. gauge.	4-ft. 8 1/2-in. gauge.	3-ft. 6-in. gauge.	2-ft. 6-in. gauge.	2-foot gauge.
New South Wales . . .	309 432	5 742	...	5 662	80	...	...
Victoria	87 884	4 627	4 505	...	...	122	...
South Australia. . . .	380 070	3 574	1 238	597	1 739	...	...
Queensland.	670 500	6 240	...	...	6 210	...	30
Western Australia . . .	975 920	4 596	...	454	4 142	...	...
Tasmania.	26 215	673	...	...	648	...	25
Northern Australia. . .	523 620	200	...	...	200	...	...
Fed. Cap. Ter.	940	5	...	5	...	...	...
Total. . .	2 974 581	25 657	5 743	6 718	13 019	122	55

the termination of the Transandine Railway in Chile where transfer is made to the broad gauge Chilean State Railways. In the latter case, however, there is good reason for the adoption of the metre gauge for the difficult line through the heart of the Andes, and it is unlikely that this will ever be changed to agree with the broad gauge lines on either side, but in some of the other cases it would seem that time will prove the desirability, if not the necessity, for a unification. In a comparatively new country where motor transport may be regarded as negligible from the competitive point of view, there is perhaps not the same necessity for avoiding double handling (with concomitant extra transit time) as there is in the older countries, but as good roads are developed and motor transport invades the railway field, those in authority will be compelled to give counsel to the arguments for minimising the expenditure and loss of efficiency arising owing to the transfers essential by reason of the break of gauge.

For reference purposes we give with this article tables showing the mileage of railways in Australia, South America and Africa on different gauges, from which it will be noticed that there is an extremely wide diversity. South America is, of course, divided into several Republics, each of which is master of its own destiny, but while the various States of Australia have certain powers they are all brought within the orbit of the Commonwealth Government for various purposes, and it should, therefore, be a relatively simple matter for them to be brought to agree to a recognised standard gauge. In Australia, both for commercial and defence purposes, it is imperative that steps should be taken to give effect to the recommandations of the Gauge Commission and of the many experts who have made reports on the various railways, as the break of gauge is one of the greatest handicaps to the effective development of railway communications in that vast continent. On the other hand, it will doubtless never be possible for the railways of South America to be reduced to a common gauge. A movement towards this was, however, made when the Paraguay Central Railway reduced its gauge to the 4 ft. 8 1/2 in. in order to permit of through traffic being worked between the Paraguayan capital and Buenos Ayres over the Argentine lines, while a further movement is on foot to-day for the widening of the 2-ft. 6-in. gauge line of the Antofagasta (Chili) & Bolivia Railway in Chile to the metre gauge so as to agree with the gauge generally adopted in Bolivia. But it would seem that for a long time to come there will be three principal gauges in the Argentine, two in Brazil, two in Peru and two in Chile, while Paraguay and Uruguay on the

standard gauge and Bolivia on the metre gauge will doubtless carry forward on their present gauge and so remain unified.

With regard to Africa, it is to be observed that well over half the railway mileage is on the 3 ft. 6 in. gauge, and that as South Africa and adjacent territories have, more or less, standardised on this gauge, through working is rendered possible. This is a decided advantage as compared with the conditions in Australia and South America to which reference has been made. As indicated in the accompanying table, which gives, on an approximate basis, the territorial distribution of railways in Africa and the mileage on the various gauges, the standard, or 4 ft. 8 1/2 in. gauge, is the widest adopted, this also being a contrast as against the two other continents discussed, where the 5 ft. 6 in. and 5 ft. 3 in. gauges are in extensive use. At the other end of the scale, Africa has a much bigger mileage on the 2-foot gauge than Australia or South America, there being close upon 2 000 miles on this gauge, of which South Africa, with nearly 1 000 miles, and Morocco, with about 800 miles, have the major portion.

RAILWAYS OF AFRICA, SHOWING MILEAGE ON VARIOUS GAUGES.

TERRITORY.	Total mileage.	4-ft. 8 1/2 in. gauge.	3-ft. 6-in. gauge.	Metre (3-ft. 3 3/8-in. gauge.	2-ft. 6-in. gauge.	2-foot gauge.
South Africa	12 555	...	11 571	...	...	984
Egypt	4 405	1 723	1 640	155	887	...
Algiers	2 815	1 467	901	412	...	35
Rhodesia	1 794	...	1 794	...	...	...
Nigeria	1 265	...	1 122	...	143	...
Tunis	1 262	317	...	945	...	...
French Sudan (1)	1 227	...	...	1 227	...	...
Belgian Congo	1 206	...	480	476	250	...
Tanganyika	1 075	...	...	1 018	...	57
Kenya and Uganda	950	...	...	950	...	...
Senegal	927	...	...	927	...	...
Angola	845	...	400	320	...	125
Morocco	815	...	...	...	...	815
Mozambique	521	...	521	...	...	...
Abyssinia	490	...	...	490	...	...
Gold Coast	470	...	460	...	...	10
Madagascar	430	...	...	430	...	...
Cameroon	425	...	...	425	...	...
Bechuanaland	394	...	394	...	...	...
Sierra Leone	344	...	...	...	344	...
Nyasaland	174	...	174	...	...	...
Mauritius	138	120	...	...	18	...
Total	34 527	3 627	19 457	7 775	1 642	2 026

(1) Includes Dahomey, Ivory Coast, etc.

The standard gauge lines are concentrated in Northern Africa, the 3 ft. 6 in. gauge is used mainly in South, West and East Africa, and the 2 ft. 6 in. gauge is found in Sierra Leone, Egypt and the Belgian Congo. From the figures given it will be noticed that from the railway point of view there is a far greater possibility of a measure of unification in Africa than in Australia or South America, but when regard is paid to the difficult physical conditions in that vast continent it would appear unlikely that, for many years to come, there will be facilities for through working except between certain territories, where intelligent anticipation of future possibilities has impelled the construction of railways on the same gauge.

[621 .116 & 669 .1]

2. — The embrittlement of boiler steel.

(*Engineering.*)

While the analysis of feed water has become, in the majority of cases, part of the general routine of large boiler plants, it must be acknowledged that the subject of boiler chemistry has received little attention at the hands of investigators. The high temperatures and pressures necessitated by modern conditions of working undoubtedly cause complex reactions and combinations to take place within the water contained in the boiler. That these reactions have an important bearing, not only on the general efficiency of the plant, but also on the life of the boiler itself, is becoming increasingly apparent. In many instances in the past, the failure of boiler plates has been ascribed to faulty material and bad workmanship. It is highly probable, however, that in a proportion of these cases, at all events, complex reactions caused by impurities in the feed water may have lain at the root of the difficulty. A peculiar form of boiler trouble, to which various terms involving the word « embrittlement », have been given, has exercised the minds of engineers for some years past. Cracks have developed along the riveted joints, below the water line, in some high-pressure steam boilers and in a few extreme cases the rivet heads have become so weakened, that it has been possible to dislodge them by a slight blow from a hammer.

A great deal of research work on this subject has been carried out, chiefly in the United States, where the trouble seems to be more prevalent than elsewhere. The investigators are however, by no means in agreement concerning the basic cause of the phenomenon and, after much discussion, two schools of thought have arisen among boiler engineers. The first is of the opinion that the feed water is the one and only agency at work, and that embrittlement of the boiler plates is due to the action of caustic soda in the water, which salt is produced by chemical action, from the sodium carbonate originally present. Waters charged with sodium carbonate become caustic when used for steam-raising purposes, and it has been definitely established that, under the conditions of temperature and pressure which prevail in the modern boiler the sodium carbonate becomes hydrolysed to sodium hydrate — caustic soda — according to the following equation :

$$Na_2\,CO_3 + H_2\,O = 2Na\,OH + CO_2$$

Messrs. R. S. Williams and V. O. Homerberg, who have collaborated in an investigation of the action of caustic soda solutions on steel, have come to the conclusion that hot concentrated solutions of sodium hydroxide gradually attack the oxides and sulphides present at the crystal boundaries of the metal. The solvent action penetrates deeper and deeper into the steel and, furthermore, if the material be subjected to stress, the slight fissures formed have a tendency to widen. The second school of

thought, while acknowledging the part played by concentrated solutions of caustic soda, maintain that there are other agencies at work in the boiler under service conditions, and that the action of the sodium hydrate is not the controlling factor. In order to examine the available evidence and to encourage further research in the subject, a sub-committee, designated « Sub-Committee No. 6 on the Embrittlement of Metals », was formed some time ago by the American Society of Mechanical Engineers. A progress report was issued recently by the chairman of the Committee, Professor A. G. Christie of Johns Hopkins University, Baltimore. Professor Christie states with truth, that while opinions differ in the matter of the causes of embrittlement, there are certain facts upon which agreement appears to be fairly general. It is acknowledged by all, for instance, that embrittlement cracks are intercrystalline in character and that the failure of the metal occurs, in practically every case, along the line of rivets.

A pioneer in this particular field of study is Professor S. W. Parr, of the University of Illinois, U. S. A.; he published a bulletin on the embrittling action of sodium hydroxide on mild steel as far back as 1917. Recently, in collaboration with Mr. F. G. Straub, he undertook a comprehensive research on the subject, and a paper presented at the annual meeting of the American Society for Testing Materials, in June, 1926, embodies the findings of these two investigators (1). A bulletin published more recently by the University of Illinois also contains an account of this same research. Messrs. Parr and Straub state definitely that, without exception, embrittling cracks follow the grain boundaries; fatigue and corrosion cracks, on the other hand, develop across the grains. Again, they find that failure occurs in plate metal of high purity having excellent mechanical properties, as well as in plates of inferior make. The chemical analyses of a number of waters used in boilers which have developed the embrittlement trouble are given in the papers. These show that sodium carbonate is the one substance which is invariably present; sulphates, on the other hand, are either absent or the amount in solution is relatively small. Although the reaction is not fully understood, sodium sulphate appears to have an inhibiting effect and, when this salt is present in any quantity, the action of the caustic soda is neutralised or, at any rate, considerably retarded.

Having ascertained, or restated, the general features of the problem, Messrs. Parr and Straub proceed to give an account of short-time laboratory experiments which they have conducted in order to obtain quantitative data, and with a view to suggesting, if possible, a remedy for the trouble. The test apparatus finally decided upon consisted essentially of a welded-steel container which held the solution, and in which steam was generated, and an external tension-producing fitting. Temperature and pressure conditions were maintained by means of an electric furnace. The materials used for the investigation were all mild steels, and specimens were subjected to tensile stress while immersed in caustic soda solution placed in the container. The test results appear to indicate that two conditions must be present simultaneously to cause embrittlement of the steel. In the first place, the actual stress must be above the yield point of the metal and, in the second, the concentration of sodium hydroxide must be in excess of 350 grammes per litre (350 000 parts per million, or 20 000 grains per U. S. A. gallon). Variations in the pressure, even up to 200 lb. per square inch, seemed to have no marked effect on the rate of embrittlement. Again, changes in its chemical composition did not appreciably alter the time required to break a specimen. The fractured test pieces were not corroded, but were covered with a thin, blue-black adherent coat of magnetic oxide of iron. Microscopic examination revealed the presence of a large number of intercrystalline cracks within the strained portion of the test piece.

The first conclusion arrived at, namely, that embrittlement only occurs when the metal is stressed beyond its yield point, is of the

(1) See *Bulletin of the Railway Congress*, April 1927 number, p. 323.

highest importance from an engineering point of view. In the course of their final remarks, the investigators make the somewhat startling statement that probably in all boiler plates the stresses at the edge of the rivet holes occasionally reach the yield point of the metal. They are of opinion that the appearance of plates and straps after they have been removed from a boiler, which has been in service, leaves little doubt that, in certain parts, the metal has been stressed above its yield point. With regard to the second factor necessary to bring about embrittlement, *i. e.*, the concentration of the caustic soda solution, the authors point out that the amount of sodium hydrate present in a boiler water seldom exceeds 1 000 grains per U. S. A. gallon, and is therefore well below the 20 000 grains required to initiate failure. They maintain, however, that the presence of caustic soda in a high-pressure boiler tends to produce a seepage of the solution into the seams between the metal surfaces. They believe that the solution gradually becomes more concentrated, and, with time, the concentration is sufficiently high to produce embrittlement. If, at the point of concentration, the localised stresses are sufficiently high, embrittlement will commence.

Turning to the prevention of embrittlement difficulties, the authors point out that the removal of the stresses of the type indicated above is hardly possible in a commercial installation. The practice of inside caulking, on the other hand, would do much to prevent embrittlement trouble if it could be carried out to something like perfection. At present the only practical proposition is the maintaining in a feed water charged with high percentages of sodium carbonate, of a ratio of sodium sulphate to sodium hydroxide somewhat in excess of 2. No absolutely definite rule can be laid down, however, and, in any case, the treatment of the water should be carefully controlled by a chemist who is fully conversant with the chemical reactions involved.

The value of Messrs. Parr and Straub's work cannot be denied. Some of the conclusions reached are, however, somewhat debatable; for instance, their theory that, at certain points within the boiler, concentration of sodium hydrate takes place until a strength in the neighbourhood of 350 grammes per litre is reached, is hardly convincing. It does not seem very probable that a solution originally containing 1 000 grains per U. S. A. gallon should become concentrated, in the manner indicated above, until it reached a strength of 20 000 grains per gallon. The position taken up by these two investigators is nevertheless somewhat strengthened by the fact that although boiler failures of this type do not appear to be confined to any one district of the United States, they have, in most cases, occurred in boilers in which the feed water contained relatively high concentrations of sodium carbonate, bicarbonate, or hydrate, and low proportions of sodium sulphate.

As stated above, many engineers while agreeing that concentrated solutions of caustic soda have been shown by experiment to produce brittleness, do not subscribe to the view that the amounts of the alkali present in a boiler under ordinary service conditions, are necessary factors in bringing about embrittlement. In opposition, the suggestion is made that gaseous hydrogen, which may be produced within the boiler, even in the absence of caustic soda, may penetrate the steel and gradually render it brittle. It is an undeniable fact that dissolved or occluded gases often have a distinctly harmful effect on the mechanical properties of metals, and scientific metallurgists are seeking to enlarge the somewhat scanty knowledge existing on this important subject. A further suggestion put forward is that excessive strains set up in the metal, when in service, may be the primary cause of embrittlement, and the source of intercrystalline cracking. Again, intergranular fracture may be developed in such materials as boiler plate by improper thermal or mechanical treatment during manufacture, or during the subsequent forging or assembling operations. In this connection, a suggestion made recently by Mr. Ulick R. Evans is of interest. He is of the opinion that the appearance of cracks round the rivet holes of boilers may possibly be due to the fact that corrosion merely widens and extends microscopic cracks, which actually existed before corrosion commenced. In sup-

port of this view, he quotes the work of Messrs. Kühnel and Marzahn, two German metallurgists, who have investigated cases of failure in steel sleepers. These workers have come to the conclusion that the trouble originates in a series of fine cracks radiating round the punched holes in the sleepers. It seems therefore, not impossible that fissures around holes, in other forms of steel work may be traced to a similar origin. On the other hand, this does not explain why, in a piece of embrittled boiler plate the rivets themselves should deteriorate.

Viewing all the published evidence, the unfortunate engineer whose boilers are subject to this peculiar form of trouble may well be puzzled. A consideration of the available date indicates, however, that two outstanding facts are prominent. One section of the scientists who have investigated the matter, appears convinced that the feed water is at the root of the trouble. Another section, on the other hand, point to undue stresses during manufacture and assembling as being the primary cause of cracking. It seems logical therefore, that the person chiefly interested, *i. e.*, the boiler user, should endeavour to counteract the evil by following the dictates of each school of thought, pending a more complete solution of the problem. When a new boiler is being constructed, the materials should be selected and controlled with the greatest care, and the workmanship strictly supervised. Again, in those cases in which the feed water employed contains some of the suspected salts, measures should be taken to eliminate or neutralise harmful ingredients on the lines suggested by Professor Parr and other workers. It is possible, of course, that as a result of continued research, the explanation of the problem may turn out to be comparatively simple and, consequently, the need for elaborate precautions will largely disappear. The trouble as it is now understood must, however, be met, and efforts should be made to turn to practical advantage the scientific data accumulated up to the present time.

[621 .133.4]

3. — Smoke box regulator for superheated steam locomotives.

Fig. 1, p 820.

When superheating has been applied to locomotives, the regulator is as a rule kept in the usual position between the boiler and the superheater. The latter forms an independent part of the boiler. When the regulator is shut, the locomotive uses the steam in the superheater, and when running with a closed regulator the superheater is empty. Certain special arrangements have had to be provided to preserve the elements.

For some time American locomotives have been fitted with a regulator in the smoke box on the outlet side of the superheater. This then forms part of the boiler and is always full of steam.

The advantages claimed for this arrangement are as follows :

The engine answers the regulator more readily. When the regulator is opened, the cylinders are filled immediately. When it is closed the driving effort ceases at once. These features are especially noticeable when starting, if the engine slips and when shunting. They have still further importance as the volume of the superheater is made relatively greater.

The auxiliaries of the locomotive can also be supplied with superheated steam at all times. This has more value in the case of American locomotives where the number of fittings is great : turbine for head light, air pumps, water pumps, mechanical stoker, grate shaking device, etc. These are estimated to take 10 to 20 % of the boiler capacity.

The life of the superheater should also be improved seeing it is always kept full of steam. It should be noted, however, that if this steam is not in movement, the protection it gives against burning of the elements is not very

effective. For the superheater to be efficiently protected, it should have steam flowing through it continuously. This would undoubtedly be more frequently the case when the locomotive is fitted with the many auxiliaries found on American engines.

Figure 1 shews the regulator combined with the header of the American Throttle Company.

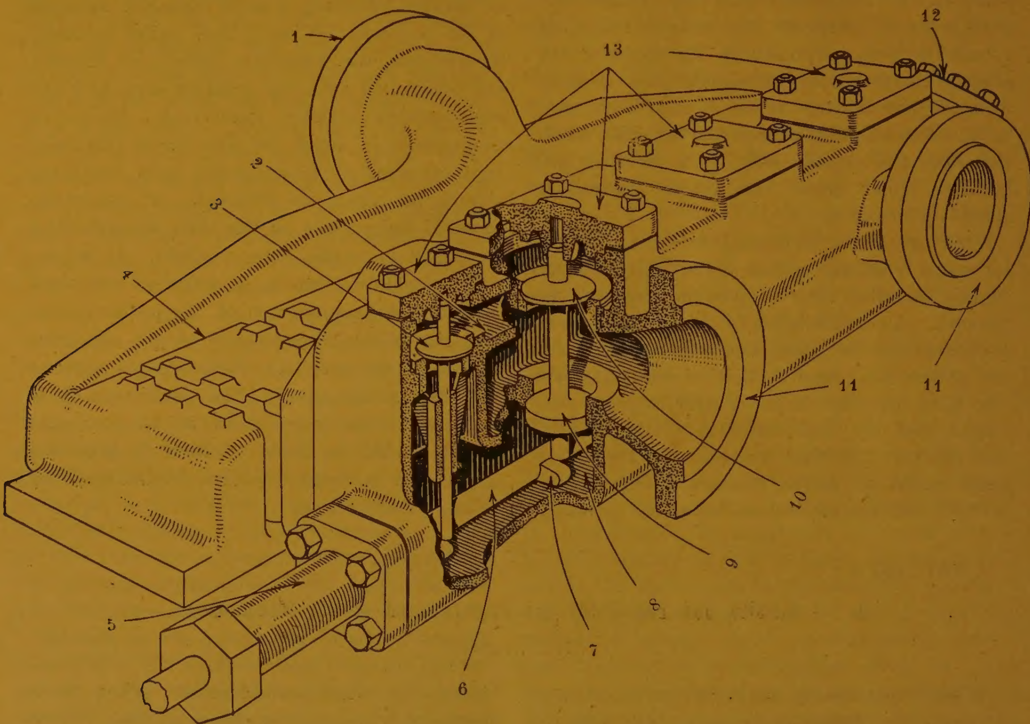

Fig. 1.

EXPLANATORY NOTE :

1.	= Dry pipe connection.	8	= Balancing chamber.
2.	= Steam compartment.	9	= Balancing piston.
3.	= Pilot valve.	10	= Throttle valve.
4.	= Header.	11	= Steam pipe connections.
5.	= Stuffing box.	12	= Flange or attachment of auxiliaries.
6.	= Operating shaft.	13	= Valve covers.
7.	= Operating cam.		

The header is cast with an additional chamber in which the regulator is housed. The regulator consists of a number of valves mounted on the same spindles as the balancing pistons. There is another smaller valve fitted in parallel which opens first and allows steam to flow into the balancing chamber under the pistons. All the valves are operated by a horizontal cam shaft.

E. M.